MODERN PHYSICS OF ROENTGENOLOGY

MUNCHERYAN

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OF
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FOR PHYSICIANS, PRE-MEDICAL STUDENTS
STUDENTS OF PHYSICS, X-RAY ENGINEERS
AND
X-RAY TECHNICIANS

BY

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Foreword By

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RESPECTFULLY DEDICATED

TO MY FRIEND

DR. COMER M. WOODWARD

FOREWORD

The book on Radiation Physics by Prof. Hrand M. Muncheryan offers not only to the student of radiation physics but to advanced thinkers, physicians and college professors as well, a practical reference book on this important subject. Prof. Muncheryan covers the field very well, the style is good, and the contents appear to be accurate. It should prove very useful in classroom work. The physical formulae, according to our own physicist, Dr. Warner, are accurate, reliable and practical. Dark room technique is given due consideration both from a practical and a technical viewpoint.

That part of the book dealing with radiation therapy is rather limited and may be accepted as the consensus of opinion of the present day. There is perhaps one exception in that part which refers to the higher voltages wherein the ability of the tube to serve satisfactorily above 400 KV. is questioned. While we ourselves have had practical experience with high voltage tubes from 500 to 1000 KV. we have found it not only practical but we believe more useful and superior to the lower voltage tube in certain conditions wherein rapid depth dosage is of importance.

We feel that this book, all in all, will prove of inestimable value to the student interested in the modern physics of radiation therapy.

ALBERT SOILAND, M. D.
Director of the Los Angeles Tumor Institute

PREFACE TO THE SECOND EDITION

This textbook, Modern Physics of Roentgenology, has grown from a course of lectures under the title, The Physics of Radiology and Procedures, given by the author for several years at the present institution. These lectures, primarily adapted to meet the needs of students pursuing academic curricula preparatory to entering a pertinent specialized course and of those preparing themselves for X-ray practice, have been published under the above second title. Since the appearance of the first edition, the supply has been exhausted twice. As a result, the author, further importuned by his friends and various other sources, has been instigated to extend the subject matter to a more complete study in the present volume.

In preparing the second edition, an effort has been made to present the material with an attitude bearing most pedagogical methods, by carefully arranging the plan that one topic leads to the other by gradual and logical steps, preparing the student to more intelligently understand the increasingly difficult successive chapters. The discussions on the subject have been presented with the view of rendering the student a thorough, comprehensive, and practical knowledge of X-rays and their applications in medicine and in specific phases of industry as well.

Due to the rapid advances in the past few years in the design and manufacture of X-ray apparatus and hence the increased flexibility of use of the equipment in the application of roentgen rays to a wider scope have made it necessary to considerably revise the section on X-ray apparatus, and to make additions to chapters on rectification, and X-ray tubes. New chapters, on units of measurement, electrical measurements, alternating currents, the character and quality of a radiograph, and X-ray and electrical protection, have been added. A supplementary section on positioning technic and roentgen therapy has been included in the appendix. The subject matter under each of the other topics has received, in general, thorough revision. However, the plan of representation of discussions of the original text has been conserved throughout.

The author believes that no account of the underlying principles of X-ray physics can dispense with the introduction of at least a few mathematical discussions and derivations, some employing also logarithmic expressions or calculus. Furthermore, a thorough understanding of these principles is, of necessity, achieved by learning their various applications, many of which are illustrated by examples based on common experience, thus bridging the gap between the theoretical and practical aspects of roentgenology.

Special endeavor is exercised to use simple language consistent with scientific writing so that any person with an elementary knowledge of physics can understand it. In this connection, it is suggested that the chapters be studied progressively and in their order of succession.

The author sincerely anticipates that the present treatise will fulfill a long-felt need in the complete presentation of the subject of X-ray technology, and trusts that it will prove useful in academic courses given by universities or colleges carrying curricula leading to some specialized field having regard to the study of X-rays. The book lends itself especially to courses in physics and pre-medical studies. It is further recommended as a reference book to the roentgenologist, and to those in X-ray profession that have acquired their knowledge through mere practice and who lack the fundamental physical foundations in the field to which they intend to adapt themselves.

The author takes this occasion to express his indebtedness to those many research workers whose literary contributions have made this second edition possible. Special obligations are due to General Electric X-Ray Corporation, and to Philips Metalix X-Ray Corporation, for their furnishing material direct from their research laboratories and illustrations of their X-ray equipment for inclusion; to Eastman Kodak Company for some of the electroplates and permission to use photographic formulae, charts, and other material from their publications; to Westinghouse X-Ray Corporation for permission to reproduce illustrations and to use information from their X-ray literature. Grateful acknowledgement is due to Central Scientific Company for Figs. 64, 68a, and 128; to Leeds and Northrop, Inc. for Fig. 26a; to the publishers of Radiography and Clinical Photography for information on specific roentgenographic considerations and for permission to reprint an abstract from Dr. S. W. Donaldson's article; to the editor of The Physical Review for permission for inclusion of Table VIII taken from the latter periodical, Vol. 27, 1926, pp. 266-76; and, to Mr. Lawsan Baylies for drawing Fig. 182.

Finally, the author takes pleasure in acknowledging his obligations to Dr. Albert Soiland, Director of the Los Angeles Tumor Institute, who reviewed the subject matter on radiation and wrote the foreword; and, to his associate-physicist Dr. A. H. Warner, who made a survey of the manuscript in general from a physical viewpoint.

H. M. MUNCHERYAN

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CHAPTER I

UNITS OF MEASUREMENT

1. The Fundamental Units.—It is of importance to have a standardized system of units whereby the calculation of quantitive work can be performed with ease, and convenience, and, at the same time, a clear comprehension can be afforded all nations in their scientific endeavor. The standards of measurements were agreed upon by seventeen nations participating in the 1875 International Metric Convention. Of these standards the metric system was adopted for use in scientific work in all countries, because of its affording a convenient method for expressing the relations between its units in multiples of ten.

The fundamental quantities chosen for the international scientific system are length, mass, and time; and, in metric system, the practical units assumed are, respectively, the centimeter, the gram, and the second, and hence the system is universally known as the C.G.S. System—named after the initial letters of these units. All electrical and magnetic units are based on C.G.S. system, the use of which is constantly increasing throughout the nations.

2. Unit of Length.—The international *meter* is a standard unit of length, and is defined as the distance between two ends of a bar of an alloy composed of 90 percent Platinum and 10 percent Iridium at a temperature of 0°C. The bar, which has an arbitrary length, is kept in the Bureau of Standards in Paris. The international prototype meters closely agree with the length of the standard meter. A meter equals exactly to 39.37 inches.

If a standard meter is divided into one-hundred equal parts, each part will represent one *centimeter,* or one-hundredth of a meter, the basic unit length in the C.G.S. system. One-thousandth of a meter, or one-tenth of a centimeter, is called a *millimeter,* and one-thousandth of a millimeter is a *micron.*

In considering the spectra of electromagnetic waves, it is very convenient to express the wave-lengths of the radiations in terms of Angstrom units (written A.U.), which is one-ten-thousandth of a micron, or one-hundred-millionth of a centimeter. A still smaller unit, generally used in the measurement of X-ray wave-lengths, gamma radiations (from radium), and cosmic rays, is the X-Unit equal to one-thousandth of an Angstrom unit. We shall have occasion to refer to the latter in the sections dealing with radiation phenomena of different spectra.

3. Unit of Mass, or Weight.—The unit of mass is the *kilogram,* which is equal to 1000 cubic centimeters (1 liter) of pure water at 4°C., the temperature of maximum density of water. This weight is the prototype of a Platinum-Iridium block kept in the International Bureau of Standards in Paris.

The *gram* is one-thousandth of a kilogram, and is equal to the weight of one cubic centimeter of water at 4° C. One-hundredth of a gram is called a centigram; and, one-thousandth of a gram, or one-tenth of a

centigram, is called a milligram. These quantities are extensively used in scientific work, especially in the measurement of chemical quantities.

4. Unit of Time.—The common unit of time based on the apparent motion of the sun around the earth is the mean solar second, or 1/86400 of the average length of time it takes for the sun to "travel" from a point on a specific meridian, around the earth, and back to the same point. In various fields of scientific work the second is consistently used as the unit of time. Derived units of time are: The minute, or 60 seconds, and the hour, or 3600 seconds.

5. Units of Pressure.—In our future discussions on discharge tubes and X-ray tubes we shall have occasion to refer to the internal pressures of the tubes under consideration. Pressure is defined as the force exerted per unit area. The *dyne* is the unit of force; and, when one dyne is applied on a square centimeter of surface the pressure is said to be 1 *bar.* One cubic centimeter of water exerts a pressure of 980 bars. A megabar is one-million bars. The atmospheric pressure at sea level is equal to 1.0132 megabars; and, expressed in terms of mercury column, an atmosphere is the pressure of a column of mercury 760 millimeters in height. In British system, this pressure is equivalent to 14.6 pounds per square inch. The most common unit of pressure used in expressing the degree of vacuum in a discharge tube is the *micron,* which is one-thousandth of a millimeter of mercury pressure.

6. Other Units of Measurement.—In C.G.S. system, the unit of force is the dyne, which is 1/980 of a gram-mass. The *erg* is the unit of work equal to one dyne-centimeter, i.e., the erg is the work done by a force of one dyne moving through a distance of one centimeter.

For measuring heat, the *gram-calorie,* or simply the *calorie,* is used as a unit of heat measurement. It is the quantity of heat required to raise the temperature of 1 Cc of water one degree centigrade. The large calorie is equal to 1000 gram-calories, and is generally used in dietetics.

There are three types of scales by which the temperature of a body can be expressed. One, the *Fahrenheit,* is chiefly used in English-speaking countries; the other is the *Centigrade* which is universally used in scientific work; and, the absolute scale (or, *Kelvin*) is the standard of temperature measurement based upon centigrade scale. The following short-cut formulae afford the conversion of one scale into the other:

To convert:

Degrees Fahrenheit to Degrees Centigrade = $(°F-32)5/9$

Degrees Centigrade to Degrees Fahrenheit = $(°C \times 9/5)+32$

Degrees Centigrade to Degrees Absolute = $°C + 273$

The zero point on the centigrade scale corresponds to 32° on the Fahrenheit scale, and the zero point on the absolute scale to -273° C.

The *specific gravity* of a substance is defined as the ratio of the weight of that substance to the weight of an equal volume of water displaced by that substance when immersed in the latter.

$$\text{Specific Gravity} = \frac{\text{Wt. of Definite Volume of Substance}}{\text{Wt. of Equal Volume of Water at } 4°\text{C.}}$$

In view of the weights of equal volumes of the substance and water being compared in defining the specific gravity of a substance, the resultant numerical value remains independent of the system of units used.

Quite closely related to specific gravity is the *density* of a substance. The density of a substance is defined as the mass per unit volume of the substance. In the C.G.S. system, the density is expressed as the number of grams per cubic centimeter of the substance.

$$\text{Density} = \frac{\text{Wt. of Substance}}{\text{Volume of Substance.}} = \frac{\text{Wt. of Substance}}{\text{Wt. of Same Volume of Water.}}$$

From the latter expression, it is obvious that the density of a substance is numerically equal to its specific gravity..

Table I gives the densities, and specific gravities of a few common substances.

Table I:—A Comparison of Specific Gravity, and Density, at 20°C.

Substance	Specific Gravity	Density—*Gm/Cc*
Aluminum..........	2.699	2.699
Copper.............	8.89	8.89
Mercury............	13.546	13.546
Brass (rolled)........	8.56	8.56
Benzin..............	0.879	0.879
Chloroform..........	1.480	1.480

7. Numbers Expressed by the Powers of Ten.—Frequently it is found more convenient to express a number by the power of ten to which that number may be raised. For example, the figures below can be written as

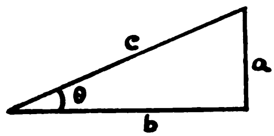
$$\begin{array}{rlr} 10 = 10^1 & (10^\circ = 1) & 0.1 = 10^{-1} \\ 100 = 10^2 & & 0.01 = 10^{-2} \\ 1000 = 10^3 & & 0.001 = 10^{-3} \\ 10{,}000 = 10^4 & & 0.0001 = 10^{-4} \\ 100{,}000 = 10^5 & & 0.00001 = 10^{-5} \\ 1{,}000{,}000 = 10^6 & & 0.000001 = 10^{-6} \end{array}$$

Examples:—To write 6,543,000 and 0.006543

$6{,}543{,}000 = 6.543 \times 10^6 = 65.43 \times 10^5 = 654.3 \times 10^4$; etc.

$0.006543 = 6543 \times 10^{-6} = 654.3 \times 10^{-5} = 65.43 \times 10^{-4}$; etc.

8. Trigonometric Functions in a Right-Angled Triangle.—If a, b, and c represent the sides of the right-angled triangle shown below, the functions of the angle θ can be given as follows:



A RIGHT-ANGLED TRIANGLE

sine θ, or $\sin\theta=\frac{a}{c}$ cosine θ, or $\cos\theta=\frac{b}{c}$

tangent θ, or $\tan\theta=\frac{a}{b}$ cotangent θ, or $\cot\theta=\frac{b}{a}$

secant θ, or $\sec\theta=\frac{c}{b}$ cosecant θ, or $\operatorname{cosec}\theta=\frac{c}{a}$

QUESTIONS ON CHAPTER I

1. (a) What are fundamental units?
   (b) How and when are the fundamental units agreed upon?
   (c) What is the universally known system of measurement? Why is it so called?
   (d) What is the standard unit of length? How is it chosen?
2. (a) Define:—A centimeter, millimeter, micron, Angstrom unit, and X-unit.
   (b) Which unit, or units, of length is used more generally for X-ray radiations? For cosmic rays?
   (c) Define the standard unit of mass. Where is it kept now?
3. (a) What units of mass are used extensively in scientific work? Define them.
   (b) What is a second? On what relative phenomenon of the sun is it based?
   (c) Name and define the unit of force; the unit of work; and, the unit of heat.
4. (a) Name the types of temperature scales, and give their relations to each other.
   (b) What is the difference between specific gravity and density?
   (c) What is a cubic centimeter? What is its relation to a gram, and to a liter of water at its maximum density?
   (d) Define the following:—One atmosphere, 1 dyne of pressure, 1.0132 megabars, 760 mm of mercury pressure, and a micron of pressure.
5. (a) A liter of salt solution weighs 1225 grams. What is the specific gravity of the solution? What will be its density?
   (b) An iron block has a specific gravity of 7.6, and weighs 2.28 kilograms. What is its volume?
6. (a) 200 Cc of water is at a temperature of 80°C. How many calories of heat does it contain? What will be its temperature in terms of Fahrenheit scale? In Absolute scale?
   (b) A kilogram weight stands on a smooth surface and covers an area of 125 square centimeters. What pressure in bars will it exert on the surface at sea level?

CHAPTER II

THE ATOMIC STRUCTURE OF MATTER

1. Matter and Energy.—The hypothesis of matter as being made up of discrete minute particles ascribes its origin to the time of Democritus, about 4th century B.C. Democritus believed that matter consisted of "atoms" (today, known as *molecules*) which were "discrete, discontinuous, indivisible, indestructible, eternal and imperishable, but separable by space." The doctrine probably reflects on a Hindu chemist, Kanada, who proposed in 1000 B.C. that "things dancing in the hot sun" were "*atoms.*" The entire concept foreshadows, nevertheless, the modern idea of the conservation of matter—a contribution which has received considerable attention in recent times in view of its affording the prediction of the behavior of the reacting elements in a chemical transmutation—either radioactive, or artificial.

Matter exists in three fundamental forms—in the form of *solid, liquid,* or *gas.* There are a number of substances that exist in all three forms. For instance, water at ordinary temperature is a liquid, and above its boiling point a gas, while below 0° centigrade it is a solid, or ice. Metals, such as iron, nickel, silver, copper, etc., assume different forms in accordance with the temperature to which they are subjected, while certain gases, such as carbon dioxide, oxygen, nitrogen, etc., can be converted into liquid under pressure and at low temperatures, and solidified when the temperature is further lowered. A thorough grasp of these fundamental yet simple principles is the basis of the advent of modern science and of the prediction of additional phenomena both in theory and practice.

On the other hand, energy is the ability to cause matter to do work. In modern interpretation, there can be drawn no distinct line to separate energy from matter, since one is convertible into the other in accordance with the formula $E = mc^2$, where m is the mass of the moving matter with a velocity c (which is in the neighborhood of the velocity of light), and E is the energy produced. Energy may be manifested in the form of motion, heat, light, magnetism, electricity, and chemical energy, and also determined by the relative position of the object.

2. The Molecule.—Since anything that occupies space may be inferred as being matter in its various forms, it is experimentally demonstrated that a given form of matter can be divided and subdivided into such small particles which are not perceptible to our senses, even by the most powerful microscope, yet these particles can exist by themselves and retain all the characteristics of the original matter from which they are derived. Such an isolated unit quantity of matter possessing all the properties of the original substance is called a *molecule.* A molecule may be an *element,* or a *compound.*

Examples of a molecule are:—

Elements		**Compounds**	
Hydrogen	H_2	Water	H_2O
Sodium	Na	Sodium Chloride	NaCl
Chlorine	Cl_2	Hydrochloric Acid	HCl
Nitrogen	N_2	Ammonia (gas)	NH_3
Sulphur	S	Sulphur Dioxide	SO_2
Iron	Fe	Iron Oxide	FeO

3. The Atom.—An *atom* is the smallest structural unit of matter or an element that may or may not stand by itself yet it is the only infinitesimally small unit quantity of matter that is capable of entering into a chemical combination.

One or more atoms of an element may stand for a molecule of the same element; and, when a molecule consists of one atom it is called a *monatomic* element. If the molecule of an element consists of two atoms, it is said to be a *diatomic* element, and if more than two atoms make up a molecule of an element, the element is known as being *polyatomic*. Such atoms may be a gas, liquid, or solid.

Examples of Such Elements are:—

Gas		**Liquid**	
Neon	Ne (monatomic)	Bromine	Br_2 (diatomic)
Hydrogen	H_2 (diatomic)	Mercury	Hg (monatomic)
Chlorine	Cl_2 (diatomic)		

Ozone................O_3 (polyatomic)

Solids

All solids are monatomic elements, normally.
Sodium................Na; Iron................Fe; Calcium................Ca.

4. The Nature and Structure of An Atom.—An atom is a complex unit structure having definite physical and chemical properties in a given element. It consists of a *nucleus* and one or a plurality of imaginary concentric circles or *orbits* around the nucleus. The nucleus of the atom bears a positive charge or charges called *protons*, surrounded by negative charges called *electrons*. An atom has as many electrons as it has protons. Therefore, an atom at rest is electrically neutral.

In an atom, some of the electrons are in the nuclear region and are called nuclear electrons, while the rest of the electrons are scattered in definite numbers in the atomic orbits and are known as orbital electrons. Approximately half of the total number of the electrons are located in the nucleus and the other half in the orbits. The nuclear electrons together with equal number of protons constitute same number of *neutrons*. A neutron is a neutral entity because of the interaction of the negative and positive charges of the electron and the proton respectively.

Examples:—An atom of Hydrogen contains a positive charge or proton in its nucleus, and a negative charge or electron in its atomic orbit.

A Helium atom has four protons and four electrons. Two of the electrons are in the nucleus and the other two are in the atomic orbit. The two nuclear electrons together with two protons constitute two neutrons in the Helium nucleus.

Lithium has seven protons in its nucleus, and seven electrons in the atom itself. Four of the electrons are in the nucleus, two in the first orbit, and one in the second orbit. Since there are four nuclear electrons in the Lithium nucleus, the latter is said to consist of four neutrons and three protons.

From the foregoing it is apparent that each atom contains as many negative charges or electrons as it has positive charges or protons, and this is why an atom at rest is electrically neutral.

The following atoms are chosen at random to illustrate the arrangement of the extranuclear electrons in their respective orbits, or, levels, and their exact number in each level.

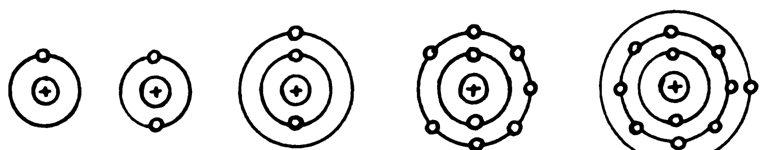


FIG. 1. ELECTRON CONFIGURATION OF SOME ATOMS.

The maximum number of electrons that a given atom may contain in its atomic levels, starting from the innermost level to the outermost, is two electrons in the first level, eight in the second, eight in the third, etc. Whenever an atom is missing less than half of the electrons on a given outermost orbit, the atom will have a valence corresponding to the number of missing electrons, and the valence will be minus. If an atom has more than half of its electrons missing on its outermost orbit, it will have a plus valence corresponding to the number of electrons remaining on that orbit (the outermost orbit).

5. The Structural Formation of A Sodium Chloride Molecule.—The

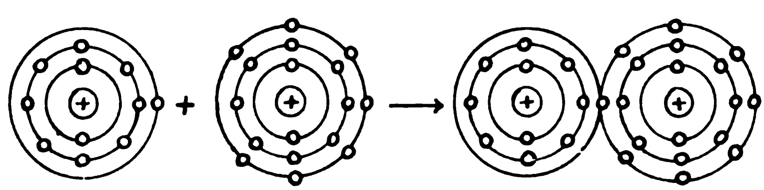


FIG. 2 FIG. 3 FIG. 4

Sodium atom in Fig. 2 has 23 protons in its nucleus, and 23 electrons in the whole atom. Twelve of the electrons are in the nucleus, two in the first orbit, eight in the second, and one in the third orbit. Having one electron in its third and outermost orbit, the Sodium atom can lend,

or give away, one electron to another atom. Such an atom as Sodium is said to have a positive valence of one.

The Chlorine atom in Fig. 3 has 35 protons in its nucleus, and 35 electrons, of which 2 are in the first level, 8 in the second, and 7 in the third level. The Chlorine atom, therefore, may take on another electron to complete its third orbit, which can only hold 8 electrons. Hence, the Chlorine atom can borrow or acquire another electron from any other atom with which it comes in close relation.

From the above illustration, as the Sodium atom can lend one electron, and the Chlorine atom can borrow one electron, when Sodium atom and Chlorine atom come together, they unite and form a molecule of Sodium Chloride, as shown in Fig. 4.

It is evident then that when atoms undergo a chemical reaction, it is the valency electron, or electrons, that enter into the holding of the atoms together in a chemical bond.

6. The Arrangement of the Electrons and Protons of Some Elements Chosen at Random.—

Element	H	He	Li	Be	B	C	N	O	F	Ne	Na	Cl
At. No.	1	2	3	4	5	6	7	8	9	10	11	17
At. Wt.	1	4	7	9	11	12	14	16	19	20	23	35
Protons	1	4	7	9	11	12	14	16	19	20	23	35
Neutrons	0	2	4	5	6	6	7	8	10	10	12	18
Nuclear Elec.	0	2	4	5	6	6	7	8	10	10	12	18
1st level	1	2	2	2	2	2	2	2	2	2	2	2
2nd level	..	..	1	2	3	4	5	6	7	8	8	8
3rd level	..	..	..	..	..	..	..	..	..	..	1	7

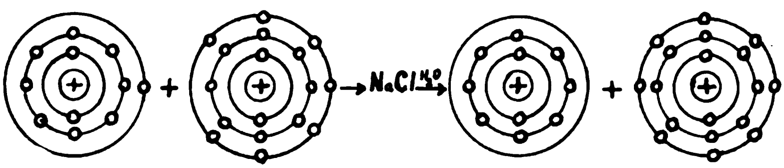
When the chemical elements are arranged in their increasing *atomic weights,* as shown in the third line from the top, and each element is consecutively numbered from one, the element with the least atomic weight, to ninety-two, the element with the greatest atomic weight, it will be found that the *atomic number* of any element will correspond to the number of orbital electrons in that element; and its atomic weight will correspond to the number of protons in its atomic nucleus. The number of nuclear electrons will correspond to the number of neutrons in that atom.

7. The Charge of An Atom.—In a previous heading, it was said that an atom at rest is electrically neutral, as it contains as many electrons as it has protons in its nucleus. But, an atom may gain one or more electrons, thereby having an excess of electrons of its normal structure. Hence, an atom at this state is said to be negatively charged. An atom losing one or more electrons and thus containing electrons less than its normal number is said to be positively charged. When, thus, the equilibrium between the positive and the negative charges is disturbed, whereby an atom gains or loses electrons, the atom is said to become electrically charged, or ionized, more properly speaking, and the process in which an atom gains electrical charge is called *ionization.*

In the example of the Sodium and Chlorine atoms combining to form a Sodium Chloride molecule, suppose the resulting molecule of Sodium

Chloride is dissolved in many times its volume of water. The Sodium Choride molecule breaks up into a Sodium atom less one electron, and into a Chlorine atom with one more electron than its normal number of electrons. This process of electron transfer from one atom to the other is a form of ionization. In this process, the metallic radical, or Sodium, becomes positively charged due to its now containing an excess of one proton, and the non-metallic radical, or Chlorine, gaining an electron from the metallic radical Sodium, becomes negatively charged. A Sodium atom thus charged is called a positive Sodium *ion,* and the Chlorine, a negative Chlorine *ion.*

The following Fig. 5 illustrates the change of neutral Sodium and Chlorine atoms to a compound, and then to ions in water:



Na°	$+\ Cl^{\circ} \longrightarrow$	$NaCl$	$\xrightarrow{H_2O}$	Na^{+}	$+\ Cl^{-}$
23 protons	35 protons	$NaCl$		23 prot.	36 elec.
23 electrons	35 electrons	$NaCl$		22 elec.	35 prot.
				1 prot.	1 elec.
				excess.	excess.

FIGURE 5.

From the above illustration it is self-evident that since Sodium lost 1 electron, it has 1 excess proton left in its nucleus, and therefore, the atom will be charged positively by 1 excess proton. Such a Sodium atom is called a positive ion. Similarly, Chlorine gaining 1 electron has now become a negative ion.

It should be clearly understood, however, that an atom gaining or losing electron does not become altered into another atom, since the number of its protons remains constant. The change in the normal number of electrons only alters an atom from one of neutrality to a charged state.

Therefore, an ion is the original atom bearing either a plus or a negative charge, or charges, depending upon the number of electrons gained, or lost.

8. The Electron and Its Nature.—The electron is the component negatively charged structural unit of every, and all atoms, or matter in general. As matter at rest is neutral due to an equilibral balance set in between an equal number of protons and electrons contained in it, it follows that the electrical charge on one proton is equal to that of one electron but opposite in electrical polarity. Although an electron has a mass approximately 1/1845 times that of a proton, yet the electrical charge that it bears is equally great to neutralize the charge on the proton. This must be the actual case, since an atom at rest having as many protons as it has electrons is in a neutral state. Another proof of

this fact is evidenced in the even interchange of positive and negative radicals in two ionized compounds in a chemical reaction.

Some of the principal properties of an electron are:—

(1) All electrons are alike regardless of the atom or the orbit from which they are derived.
(2) An electron always bears a negative charge.
(3) Electrons in an atom are in motion around the nucleus similar to that of planets around the sun.
(4) Electrons can exist and move independently of the protons, or of the same atom.
(5) An electron has a mass of 1/1845th of that of a proton, or, 9.03×10^{-28} gram.
(6) The speed of an electron varies from 1/20th to full speed of light; i.e., approximately from 1,500,000,000 to 30,000,000,000 cms. per second.
(7) Electrons can be made to travel at great speed under electric potentials, or voltage. The greater the impressed voltage the faster the electrons travel.
(8) The magnitude of the electronic charge is 4.77×10^{-10} electrostatic units, or 1.591×10^{-19} coulomb.
(9) Electrons are a source of energy—chemical, thermal, radiant, electrical, physiological, and, indirectly, mechanical.

9. The Electron As A Unit Quantity of Electricity.—Whenever atoms are dissociated whereby a continuous supply of electrons is produced, and which electrons are made to travel through a suitable metallic conductor, a current of electricity is the result. In metallic substances, the electrical conductivity is due to the presence of an atmosphere of free electrons in motion. The effect of the application of an electrical potential (voltage) is to impress a definite average velocity of drift on these electrons in the direction of the electrical potential gradient. This drifting of electrons constitutes the electric current, indicating that electricity is carried only by the migration of electrons. Since the electrons bear only negative charges, it follows that in metals only the negative charges travel axially along the metal.

The energy of the heat motion of the internal free electrons will increase with rising temperatures, and at sufficiently high temperatures this energy will increase to the extent of carrying these electrons out through the surface of the hot conductor. Under such conditions, the heated body is capable of discharging negative but not positive electricity, since no protons are moved during the process. Such an escape of negative electricity (electrons) from bodies at high temperatures is analogous with the evaporation of the molecules of a solid, or a liquid under heat. This process of "evaporation of electricity" is sometimes known as "Edison Effect", as he was one of the first investigators to notice this phenomenon. (In a later chapter this effect will be taken up in detail.)

However, if positive charges or protons are made to move, atoms move, too, and this phenomenon is further evidenced in the ionization of gases, and solids dissolved in liquids. Thus, when an atom ionizes under favorable conditions, such as in an electric discharge tube, or in an electro-

lytic process, not only the electrons move but the atoms move, too. A gas, liquid, or a vapor of solid bodies can be made to ionize by passing a current of electricity through it.

The speed with which an ionized atom travels is far less than the speed of an electron, since the mass of the former is many times greater than that of an electron.

In the following diagrams, Fig. 6 illustrates the process of ionization in gases under reduced pressures, and Fig. 7 shows how copper is made to deposit on the carbon electrode in a solution of Copper Sulphate.

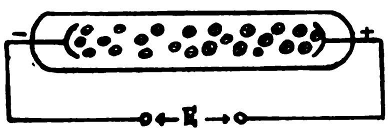


FIG. 6. DISCHARGE THROUGH NEON ATOMS

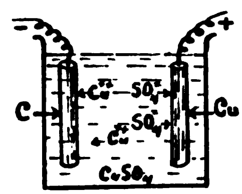


FIG. 7. ELECTROPLATING CARBON WITH COPPER

In Fig. 6, as the potential is applied to the electrodes at each end of the glass tube, electrons will aggregate at the negative terminal, or the *cathode,* but soon they will be dispersed or repelled towards the positive electrode, or the *anode.* On their way, these electrons, colliding with the atoms of the gas, will knock off one or more electrons from the outer orbit of the atom. As the atom loses one electron, or electrons, it will be charged positively, or it will simply become a positive ion, which will be attracted towards the cathode from which it will liberate an electron.

The energy required to ionize an atom depends upon the energy level of the electron displaced, i.e., from which orbit the electron makes a transition. In referring to ionization, usually we refer to the more loosely bound valency electrons in the outermost orbit of the atom. Since the inner electronic shells, or levels, of the atom are complete, the energy required to remove an electron from such orbits in heavy atoms is from 1000 to 100,000 times that required to displace one from the outer orbits.

We have already mentioned that the speed, hence the energy, of an electron is dependent on the applied voltage. If V is the voltage impressed on an electron, then it acquires a kinetic energy, *K.E.,* (energy of motion) in accordance with the following formula:

$$\text{K.E.} = \tfrac{1}{2}mv^2 = \frac{Ve}{300}\text{ergs.} \qquad (1)$$

where, V is the applied voltage, e is the charge and m the mass of the electron, and v is the velocity of the electron in centimeters.

The velocity of the electron will be given as

$$v=\sqrt{\frac{2Ve}{300m}} \quad \text{cms./second.} \tag{2}$$

Example:—What velocity is acquired by an electron impressed with a potential of 1 volt?

$$v=\sqrt{\frac{2Ve}{300m}}=\sqrt{\frac{2\times 1\times 4.77\times 10^{-10}}{300\times 9\times 10^{-28}}}$$

$$=\sqrt{\frac{9.54\times 10^{-10}}{27\times 10^{-26}}}=\sqrt{\frac{9.54\times 10^{-10}\times 10^{26}}{27}}$$

$$=\sqrt{\frac{10^{16}}{3}}=5.77\times 10^{7} \text{ cms./second.} \quad \textit{Ans. } \text{(approx.)}$$

It is obvious in the above relations that the higher the applied voltage in a discharge tube the faster the electron will travel. Since the kinetic energy of a moving electron varies with its velocity, the higher the velocity the greater the energy acquired by the electron, as shown by formula (1).

Most of the electrons, after colliding with atoms, or the walls of the discharge tube, will eventually reach the anode, from which they will be transferred as a stream of electricity through the circuit wires. The remaining positive ions in the tube will produce a glow of positive column, forming a path for the passage of electric discharge. This phase will be further discussed in the chapter on "Discharge In Gases, and Vacua."

Figure 7 represents the process of ionization and electrodeposition of an electrolyte, such as Copper Sulphate solution. The Copper Sulphate first dissociates into a Copper ion with two positive charges, and into a Sulphate radical bearing two negative charges gained from the Copper atom. The Carbon terminal being of a negative polarity will attract the positive Copper ions, the latter depositing on its surface as the original Copper atoms. The Sulphate ions reaching the Copper anode will react with it forming Copper Sulphate, which will compensate for the Copper Sulphate removed from the solution by electrolysis. The rate of travel of positive ions in an electrolyte, however, is very low—approximately one centimeter every several minutes.

The amount of Copper deposited on the Carbon electrode is directly proportional to the magnitude of the current passing through the solution, and the time the current is prolonged. This is Faraday's law, and may be expressed as

$$\text{Mass Deposited} \propto Q$$

where Q is the quantity of charge in coulombs. Written in a different form

$$Q = It \tag{3}$$

where, I is the current in amperes, and t is the time in seconds.

It is experimentally found that it takes about 96,500 coulombs to deposit 1 gram-equivalent of a substance. The gram-equivalent of a compound is equal to the molecular weight of that compound divided by the valence of the metallic radical, and the gram-equivalent of an element is equal to its atomic weight divided by its valence. This gives the number of grams deposited by 96,500 coulombs of charge. The latter quantity is known as one *faraday,* after Faraday.

The following examples will further illustrate the relation between the flow of charge through an electrolyte and the amount of solid deposited:

Example:—How much Copper will deposit on a Carbon electrode in 20 minutes if a current of 50 amperes passes through a solution of Copper Sulphate? (The atomic weight of Copper is 63.57 and its valence is 2. Therefore, its gram-equivalent weight is 31.78 grams.)

We are given:
$$t = 20 \times 60 = 1200 \text{ seconds.}$$
$$I = 50 \text{ Amperes.}$$
$$Q = ?$$

From equation (3), the quantity of electricity in coulombs running for 20 minutes will be

$$\begin{aligned} Q &= It \\ &= 50 \times 1200 \\ &= 60{,}000 \text{ coulombs.} \end{aligned}$$

Since it takes 96,500 coulombs to deposit 1 gram-equivalent of Copper from its solution, then 60,000 coulombs will deposit Copper in the following ratio:

$$96{,}500 : 31.78 :: 60{,}000 : X$$
where, X = Grams of Copper Deposited.

and,
$$X = \frac{31.78 \times 60{,}000}{96{,}500}$$

$$= 19.7 \text{ Grams.} \quad \textit{Ans.}$$

It is well to keep in mind that the same quantity of electricity that deposits 1 gram-equivalent of Copper from its solution will deposit, for instance, over three times this weight of Silver, and only one-fourth as much of Oxygen. The weight deposited, then, is shown as being dependent on the atomic weight and the valence of the substance.

QUESTIONS ON CHAPTER II

1. (a) Define and give examples of each:—Matter, energy, molecule, atom, monatomic element, diatomic element, atomic orbit, energy level, and neutron.
   (b) What is the structure of an atom? Explain fully.
   (c) Draw the structural form of a Carbon and an Oxygen atom, and combine them to form a Carbon Dioxide (CO_2) molecule.
2. (a) Explain fully the nature of an electron, listing its principal properties.
   (b) Discuss fully the charge of an atom at rest, and state when an atom is charged positively, and when it is charged negatively.
   (c) How does electricity result from an atom? Explain.
3. (a) Name five elements and give their exact atomic numbers, atomic weights, number of nuclear electrons, the number of neutrons, and the number of orbital electrons in the 1st, 2nd, or 3rd orbital levels.
   (b) When do positive charges move? Explain fully by electron theory, giving an example and a diagram.
   (c) Do positive charges move as fast as electrons? Why?
   (d) What is Edison Effect? Discuss.
4. If an atom of an element were made to gain one proton the atom would have two complete orbits and as many orbital electrons as it has nuclear electrons.
   (a) What will be the atomic number of the atom?
   (b) What will be the atomic weight of the atom?
   (c) How many nuclear electrons will it have?
   (d) How many neutrons will it have?
   (e) How many protons will it have?
   (f) What will be its present valence?
   (g) Name the atom.
   (h) What was the atomic number of the original atom?
   (i) What was the atomic weight of the original atom?
5. What must be the voltage impressed on an electron in order to give the latter a velocity of 1.5×10^{10} cms. per second? What will be the kinetic energy of the electron?
6. How long will it take to deposit 26.97 grams of Silver from a Silver Nitrate solution, if a current of 40 amperes is running through the electrolyte? The atomic weight of Silver is 107.88, and its valence is 1.

CHAPTER III

MAGNETISM AND RELATED PHENOMENA

The most primitive impetus to the development of instruments for directional indication in naval and terrestrial travel came with the discovery of Lodestone, also known as Magnetite. Lodestone, a very crude ore, is a composite oxide of iron having the chemical formula $FeO.Fe_2O_3$, which has the peculiar property of attracting bits of iron when brought near it. Aside from exerting an attracting force on iron particles, Lodestones induce the same peculiar property in iron when rubbed with them. This property of the ore attracting particles of iron towards itself is known as *magnetism*.

It is unknown just when magnetism was discovered, but it is said that Chinese have used Lodestones as early as second century B.C. In the eleventh century, magnets were put into use as directional guides in navigation. However, it was not until the year 1600, when an Englishman, William Gilbert, published his first treatise, De Magnete, on the fundamentals of magnetism, pointing out for the first time, that the Earth behaves as a gigantic magnet, and therefore, in its field, magnetic substances, when free to move, orient themselves along the directional force of the field.

The metals which exhibit the characteristic property of a Lodestone are called magnetic substances. Iron, Nickel, Cobalt, and their alloys can be magnetized to a considerable extent; and, Manganese, Aluminum, and Copper, while non-magnetic to an appreciable degree in their elemental forms, become highly magnetic when alloyed with each other and exposed to the influence of a strong magnetizing force such as afforded by an electromagnet, which is usually a solenoid made of a coil of wire carrying relatively a large current. Magnets produced in this manner are known as artificial magnets, as differentiated from the natural magnets, or Lodestones. In the accompanying sections, we shall see, as far as knowledge at the time of this writing is concerned, the more probable cause and nature of magnetism in the light of electronic whirl in the atomic shells of magnetic substances.

1. The Earth and Magnetic Substances.—Magnetism is a natural property of Iron and related substances, such as Nickel and Cobalt, and their alloys. Naturally found magnets are known as Lodestones, which are Iron ores containing Silicon, Sand, Aluminum, and Zinc; and, sometimes they are found in association with Gold, Silver, and Copper. The Earth, due to the generation of billion-ampere currents by the molten mass of radium-like metallic substances occupying its interior, and hence an enormous production of magnetism, is considered to be the largest magnet ever known.

When a bar magnet is so suspended in air by means of a fiber that it can swing freely about its vertical axis, the magnet will orient itself in more or less north-and-south direction. The end of the magnet pointing to the North is called the north-seeking pole, or simply the *north pole*, and the opposite end, which points to the south pole of the Earth, is called the *south pole* of the magnet. This is an indication that the Earth has its north and south magnetic poles respectively in proximity of its south and north geographical poles, the magnetic pole being located about 800 to 1100 miles from the corresponding geographical pole.

The pointing of the north-pole of a magnet to the northern extremity of the Earth's axis of rotation is utilized in the construction of instruments for directional indication. One of the most common of these instruments is the magnetic compass, which is made of a light piece of permanently magnetized steel formed in the shape of an arrow and mounted, free to move, on a sharp point pivoted centrally in a cylindrical metallic case. The arrow head of the magnet points in the general direction of the geographical north pole, and the other end points to the south pole. An imaginary perpendicular plane cutting this needle at right angles will approximately lie in an East-to-West direction. Such an instrument is widely used on sea-going vessels, and air-ships, and frequently on vehicles travelling on land.

2. Magnetic Substances and Their Effects.—The principal magnetic substances which are in common use are Iron, Nickel, Cobalt, Aluminum, and their alloys. Permalloy is an alloy containing Iron 78.5%, and Nickel 21.5%, having a magnetization power many times more than the iron alone. Permivar is the commercial name for another alloy of iron containing Cobalt and Nickel. Powerful permanent magnets are generally made of Cobalt and Steel, while Tungsten-Steel combination is also used quite frequently for this purpose. These metals have highly magnetic characteristics, and, therefore, are known as ferromagnetic substances. Some substances, which are only slightly magnetic in their elemental states, such as Manganese, Aluminum, and Copper, become magnetized to a considerable extent when alloyed with iron. Alnico is an alloy of Aluminum, Nickel, and Cobalt, and is claimed to have a lifting power of fifty times its weight.

Magnetic substances are magnetized either permanently or temporarily under a magnetic influence. Those that are permanently magnetized are made of hard Iron, or Steel, or of an alloy of Steel and either one of Manganese, Tungsten, Nickel, or Cobalt. Magnets made of these alloys retain most of their magnetism for a considerably long period after the magnetizing field is removed. A bar magnet, and a horse-shoe magnet are examples of permanent magnets. Temporary magnets become easily magnetized and retain their magnetism as long as they are in the influence of the magnetizing force, or field, but as soon as this field is removed they lose their magnetism. Such magnets are usually made of laminated sheets of soft iron. They are extensively used in the manufacture of electric door-bells, induction coils, transformers, in telegraphy and telephony, in motors and generators, and in a variety of other apparatus used in medical treatment.

The magnetic effect is found to act through most substances. Unlike electricity, there is not any known substance that can effect insulation to a magnetic field. Small bits of iron placed on a thick plate glass will follow the path of a strong bar magnet moved back and forth underneath the glass. The phenomenon of the traversing of the magnetic force through the glass plate is a bold manifestation of the undeterred magnetic influence. When the glass is replaced preferably by a thick sheet of iron, the effect is markedly decreased, indicating that the sheet iron acts as a partial screen to magnetism, by spreading the magnetic force throughout its interior.

3. The Magnetic Poles.—In the foregoing section we have seen that there are two types of magnetic poles—a north-seeking pole, and a south-seeking pole. Furthermore, the poles of the same magnet are of equal strengths but of opposite polarities; and, the intensity of each pole is usually concentrated at a region a short distance from the corresponding pole face. The individual north or south poles never exist by themselves; whenever there is a north pole at one end of a piece of magnetized iron bar there always exists a corresponding south pole at the other end. Cutting the magnetic bar into two does not result in the separation of the two poles, but each half becomes a complete magnet having a north, and a south pole of equal strengths. That is, magnetic poles do not exist free, and that the character of the magnetic substance is influenced by the magnitude and degree of polarization of the molecules constituting it.

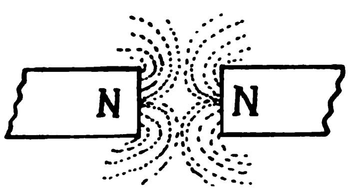


FIG. 8. REPULSION OF LIKE MAGNETIC POLES

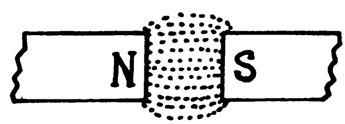


FIG. 9. ATTRACTION OF UNLIKE MAGNETIC POLES

If two bar magnets, each suspended in air by a thread from its midpoint and is free to rotate, are brought close to each other, it will be observed that when either the two north poles or the two south poles are near together there will be a repulsion between the two magnets, Fig. 8. If the north pole of one of the magnets occurs in the vicinity of the south pole of the other, there occurs an attraction between the magnets, Fig. 9, indicating that *like magnetic poles repel and unlike attract.*

4. The Force Between Two Magnetic Poles.—Coulomb, using the same analogy of reasoning as in his experiments on electric charges, has deduced that the force of attraction or repulsion between two given magnetic poles is proportional to the product of the pole strengths, and inversely proportional to the square of the distance separating the poles. Stated in a different manner, the force exerted, for instance, by two equal poles is twice that exerted by a single pole, and that increasing the distance between the poles decreases the force of attraction or

repulsion, as given by the formula

$$F = \frac{h_1 h_2}{\mu d^2} \tag{4a}$$

in which, h_1 and h_2 stand for individual pole strengths, d is the distance (in centimeters) between the poles, μ is the permeability of the medium separating the poles, and F is the force in dynes exerted by the poles. The permeability for air, or vacuum, is unity, and therefore, since in our discussion the magnets were suspended in air, the above equation may take the form

$$F = \frac{h_1 h_2}{d^2} \tag{4b}$$

From the above consideration, we may define a unit pole as one that will exert a force of one dyne on a unit magnetic like pole placed one centimeter from it (in air). In practice, however, it is not possible to have just one pole, and hence, our discussion of the unit magnetic pole should apply to a hypothetical magnet of infinite length, since when the magnet is short the force exerted by the opposite pole becomes significant. The application of the above formula, therefore, is limited to relatively long magnets.

Example:—A horse-shoe magnet has pole strengths of $+65$ and -65. The poles are separated from each other by 3 centimeters in air. What will be the force F between the poles?

Since the space between the poles is air, then the factor μ is unity, and we have

$$F = \frac{h_1 h_2}{\mu d^2} = \frac{65 \times 65}{1 \times 3^2}$$

$$= \frac{4225}{9} = 469.44 \text{ dynes.} \qquad \textit{Ans.}$$

5. The Elemental Theory of Magnetism; The Bohr Magneton.—Substantial support is had by the modern view that the fundamental unit of magnetism is constituent of the individual atom of a magnetic substance. According to this theory, each molecule of iron is a complete magnet in itself, in that, due to the planetary electronic whirl about the nucleus of each atom, there is set up in space some sort of strained condition, or disturbance, recognized externally as magnetism. Indeed, in a bar of magnetized iron the orbital plane of the revolving electron is so oriented as to contribute its share to the rest of the planes similarly aligned, and creating distortions externally behaving as if radiated from a point on the north pole of the magnet, projected in an arc into infinity,

and finally focused perpendiciularly to a point on the south pole joining the axis of the two poles, Fig. 11.

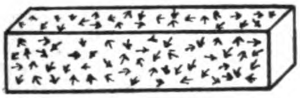


FIG. 10. AN UNMAGNETIZED BAR OF IRON.

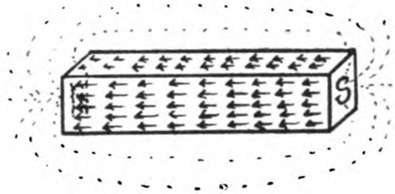


FIG. 11. A MAGNETIZED IRON BAR.

It is shown experimentally that the electrons revolving in an atom produce effects analogous to electric currents flowing in such orbits as characterized by the positions of these electrons. Moreover, it is observed that a moving current in a conductor creates a magnetic field about it. A whirling electron, therefore, will constitute a current in a loop of same diameter as the electronic orbit, and the magnetic field intensity produced within the loop will constitute the strength of an elementary magnet. Hence, in the atoms of a given magnetic substance, orienting all such electron systems consistently in the same plane of phase so that all the electrons responsible for the formation of these miniature molecular magnets will revolve in the same direction produces a magnet. Obviously then, in an unmagnetized piece of iron bar, the orbital motions of the different electron systems have haphazard directions, and thus, the magnetic effect due to them is nullified intra-orbitally.

In Fig. 12, below, the tiny circles represent the paths of rotation of the electrons in random directions in the atomic orbits of an unmagnetized bar of iron, while in Fig. 13 is shown the alignment and the consistency of unidirectional rotations of the electrons in their normal orbits in a magnetized bar of iron.

FIG. 12. WHIRLING OF ELECTRONS IN IRON BAR.

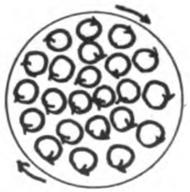


FIG. 13. ALIGNMENT OF ELECTRONS IN A MAGNET.

When a permanent magnet is vigorously heated, the alignment of the electronic system will be disturbed, and the forces acting between the molecules will become ineffective as the temperature is exceeded a certain point known as Curie point, at which the velocity distribution of the electrons becomes so enormous as to affect the continuity of the specific heat of the metal. This point for Iron is approximately 745°, and for Nickel 375°.

It will be further observed that an electron rotating in the orbit of an atom possesses angular momentum, which is an attribute of magnetism as current-magnetic field is what to a moving electric charge. From these considerations, Gerlach and Stern have made important observations of the magnetic properties of various atoms. In their experiments, the vaporized molecules of the metal, such as Silver, to be investigated are allowed to pass through a narrow slit in vacuum, and the resulting beam subjected to the action of a strong non-homogeneous magnetic field acting at right angles to the beam. The molecules, having been deflected by the rapidly-changing magnetic field, are made to impinge on a screen on which they make visible marks by condensing on it. On the consideration of classical theory, the deflection of the vaporized molecules must be proportional to the component of the magnetic moment associated with a single atom.

In deriving the simple relation between the angular momentum of the electron and its magnetic moment, then, it will be observed that the equivalent current I, due to the electron charge e describing an orbit (elliptical) around the nucleus and making a revolutionary frequency f, is given as

$$I = ef \tag{5a}$$

where, I and e are given in electrostatic units. From known relations of current-magnetic fields we find that a current I flowing in an orbit enclosing an area A produces a magnetic moment M_p given by

$$M_p = \frac{efA}{C} \tag{5b}$$

in which, M_p is given in electromagnetic units in view of the insertion of the conversion factor C, the speed of light. But, in the case of circular orbit of radius r, the angular momentum is given by the relation

$$M_\theta = mur = 2\pi rf.mr = 2m.f.A \tag{5c}$$

and, substituting the value of f of the last term from equation (5c) in the equation (5b), we obtain for the magnetic moment

$$M_p = \frac{eA.M_\theta}{2\,CmA}$$

$$M_p = \frac{eM_\theta}{2mC} \tag{5d}$$

Hence, according to Bohr quantum theory, the permitted values of M_θ for a single electron moving in an orbit, whose plane is necessarily perpendicular to the magnetic field, are

$$M_\theta = \frac{nh}{2\pi} \tag{5e}$$

where n is the orbital quantum number, and h is Planck's constant equal to 6.55 x 10^{-27} erg-second. The electron may revolve in the nth orbit in either direction—the direction of revolution affecting only the positions of the north and south poles of the elementary magnet.

Now, substituting, then, $\frac{nh}{2\pi}$ for M_θ in equation (5d), we obtain

for the magnetic moment of a single electron in revolution in the nth orbit around the nucleus

$$M_p = \frac{n\epsilon h}{4\pi mC} \tag{5f}$$

The quantity M_p, frequently referred to as the "Bohr Magneton," is the polar strength of an elementary magnet, and is numerically equal to 9.218 x 10^{-21} erg per gauss. From the foregoing it is apparent then that an atom in orientation in a magnetic field assumes a magnetic moment whose component exactly amounts to one magneton. If, now, this quantity is multiplied by Avogadro's number, we obtain per mole of an univalent element of single quantum atoms a magnetic moment of 5590 ergs per gauss.

6. Magnetic Field, Intensity, and Flux Density.—In the preceding section it was shown that the unidirectional alignment of all like polar planes of the elementary magnets in a magnetic substance would produce a magnet. The space around the magnet confining the magnetic disturbances evoked by the moving electric fields of the electrons giving rise to the elementary magnets is usually known as the *field* of that magnet. Around a magnetized bar of iron, the magnetic field is more intense at the poles; and, the field starts from the north pole, diverges in a closed path around the entire length of the magnet and finally converges perpendicularly along the surface of the south pole. This field may exist about the whole axial length and the peripherum of a coil of wire forming a helix and carrying a current. The direction of the magnetic field may be detected by placing a magnetic compass in the neighborhood of the coil and moving it about the coil. The north-seeking pole of the magnetic needle will deflect in the same direction as the magnetic field at any point around the coil.

The strength of the magnetic field is known as the *magnetic intensity.* A unit magnetic intensity is one which is produced by a unit north pole placed 1 cm from another north magnetic pole of unit strength and repelled by a force of 1 dyne. The intensity of the magnetic field, in general, is determined by a consideration of a unit north pole of strength h_1 c.g.s. units, placed 1 cm from a magnet having a pole strength of h_2, and

acted upon by the field R of the magnet with a force of F dynes, as given by the relation

$$F = Rh \tag{6a}$$

and,

$$R = \frac{F}{h_1} = \frac{h_2}{\mu d^2} \tag{6b}$$

where, μ is the permeability of the medium between the magnetic poles, separated by d centimeters, and F is the force in dynes between the two magnetic poles under consideration. Since the permeability of a non-magnetic medium such as air is unity, then the force between the two magnetic poles will be given by the expression

$$F = \pm\frac{h_1 h_2}{d^2} \tag{4b}$$

This is known as expressing Coulomb's *Inverse Square Law.* The plus and minus signs before the term on the right-hand side of the equation denote that the force intermediate the poles may be respectively either one of repulsion or attraction.

Referring again to the elementary magnet, when a group of such magnets are aligned in a row along the entire axial length of a bar magnet, we have already seen that the magnetic disturbance produced external to the magnet behaves as if originated from a point source on the north magnetic pole, radiated in an arc, and contracted back to the corresponding point on the south pole of the magnet. For purposes of analysis, it is convenient to refer to this disturbance as a *line of force,* and thus to assign to a given magnet a definite number of lines of force characterized by the strength of either one of its poles and the cross-sectional area of its pole face. Each line of force is also known as a *maxwell.* The total lines of force issuing from a given magnetic pole face is called the *magnetic flux,* and the number of lines of force per square centimeter at any plane at right angles to the magnetic field is called the *flux density* at that region; the unit field strength or flux density is called the *gauss.*

To further explain the relations of these magnetic terms, let us assume that a magnet has, for instance, 16,000 lines of force at its pole face having an area of 4 square centimeters. The magnet is then said to have a total flux of 16,000 maxwells, and the magnetic intensity of the pole will be 4000 lines of force, or maxwells, per square centimeter.

In a medium of uniform magnetic field, the total magnetic flux ϕ is determined by the relation

$$\phi = BA \text{ maxwells.} \tag{6c}$$

and,

$$B = \frac{\phi}{A} \text{ gausses.} \tag{6d}$$

where, B is the flux density in gausses, and A the area in square centimeters measured at right angles to the magnetic field.

Examples:— (a) A magnet has a total flux of 1,600,000 lines of force and a pole face area of 40 square centimeters. What is the flux density?

According to equation (6d), we have

$$B = \frac{\phi}{A} \quad \text{where,} \quad \begin{array}{l}\phi = 1{,}600{,}000 \text{ maxwells.}\\ A = 40 \text{ sq. cms.}\end{array}$$

$$= \frac{1{,}600{,}000}{40} = 40{,}000 \text{ gausses.} \qquad \textit{Ans.}$$

(b) What must be the area of a pole face so that it can have a flux density of 18,000 gausses, if it has a total flux of 648,000 maxwells?

From equation (6c), we may write

$$A = \frac{\phi}{B} = \frac{648{,}000}{18{,}000} = 36 \text{ sq. cms.} \qquad \textit{Ans.}$$

QUESTIONS ON CHAPTER III

1. (a) What is magnetism? Discuss fully.
   (b) What are natural magnets? Artificial magnets?
   (c) Describe a magnetic compass. What is it used for?
   (d) What general property or properties has the Earth?
2. (a) Differentiate the magnetic poles of the Earth from its geographic poles.
   (b) Give five examples of magnetic substances.
   (c) What are temporary magnets? How are they made?
   (d) What are permanent magnets? How are they made?
3. (a) Through what substances can magnetic forces act?
   (b) What substances can partially screen the magnetic forces?
   (c) How many poles has a magnetized bar of iron? Name them.
   (d) If two magnets are placed side by side, when do they attract each other? When do they repel each other?
4. (a) How long can induced magnetism be retained in different substances? Name the substances, and illustrate.
   (b) What kind of metal can best retain induced magnetism after the magnetizing force is removed? Why?
5. Illustrate with diagrams the complete explanation of the molecular theory of magnetized substances. What is a magneton? Discuss.
6. (a) State the law of force between two magnetic poles.
   (b) Give the formula of this law, and compute the value of the force between the poles if each of the factors involved is equal to unity.
   (c) What name is given to the unit force between the poles?

7. A horse-shoe magnet has pole strengths of —90 and +90. The poles are separated from each other by 3.5 cms. in air. Find the force between the poles.

8. (a) What are magnetic lines of force?
   (b) Define:—Maxwell, flux density, gauss, flux, pole face, magneton, and a molecular magnet.
   (c) If an iron pin head is placed midway between the poles of a horse-shoe magnet, to which pole will it be attracted? Why? Explain.

9. (a) If a magnet has 15,000 maxwells and a pole face area of 7.5 sq. cms., what is the flux density?
   (b) If the flux density of a magnet is 12,000 gausses and the pole face has an area of 4 sq. cms., find the flux in maxwells.

CHAPTER IV

ELECTROSTATICS

1. Positive and Negative Electrification in Non-Metallic Bodies.—The simplest state of electricity is manifested in static electricity, which is electricity at rest. Almost all substances possess the characteristic property of becoming electrified by friction. The characteristic substances which are easily electrified are amber, ebony, wax, hard rubber, sulphur, etc., and such electrification is evidenced in the fact that when objects are electrified they acquire the property of attracting or repelling each other. Static electricity can also be accomplished by friction between a liquid and a metallic substance. Gasoline, for example, electrifies the container with which it makes a frictional contact. That is why a gasoline truck is grounded by an iron chain to neutralize the electrical charge on the gasoline tank produced by the friction between the gasoline and the walls of the tank.

When hard rubber is rubbed with a woolen cloth, it becomes electrically charged. If two such electrified hard rubber rods are made to swing freely in air, by tying a string to the middle portion of each rod, it will be noticed that the ends of the rods that are rubbed with the woolen cloth, when brought together, will repel each other, as shown in Fig. 14, indicating that both rods have been electrified by wool with the same kind of electrical charge, or with similar electrical polarity. But, if a glass rod, after having been rubbed with silk, is brought near the electified end of one of these rods, the hard rubber and the glass rod will attract each other, as in Fig. 15, below. Conclusion is drawn from this fact that there must be two states of electrification and that: *Like electrifications repel and unlike attract each other.*

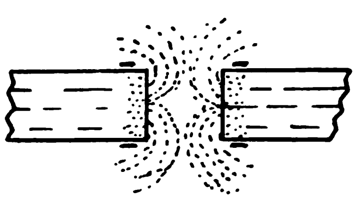


FIG. 14.

HARD RUBBER HARD RUBBER

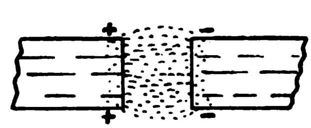


FIG. 15.

GLASS HARD RUBBER

Therefore, the kind of electricity acquired by the glass rod after being rubbed with silk is called positive, and the kind found on the hard rubber rod rubbed with wool is called negative electricity.

The use of static electricity as useful energy is becoming popular in operatinig huge voltage generators used for the investigation of the

atomic structure and transmutational phenomena. However, static electricity is impractical as a source for lighting electric lamps, or for operating motors.

2. Electrical Conductors and Insulators.—While there are no conductors for magnetism, almost all metallic substances are good conductors of electricity. But, it must be well clear in mind that when a hard rubber rod, or, a glass rod, is electrified, only that portion of the rod that is rubbed with the cloth becomes charged. The electricity thus produced does not flow from one end of the rod to the other, because, hard rubber, or glass, is not a conductor of electricity. In the case of a metallic body, the electricity can travel from one end of the conductor to the other end, and when the conductor is grounded, the electricity will flow off to the ground. Hence, all substances of metallic nature are best conductors of electricity, while glass, hard rubber, mica, amber, etc., are poor conductors and good insulators of electric currents.

Table II, below, gives a list of conductors, and non-conductors or insulators, of electricity. The metals are arranged in the order of their decreasing conductivity, while the insulators are arranged in the order of their decreasing dielectic strengths.

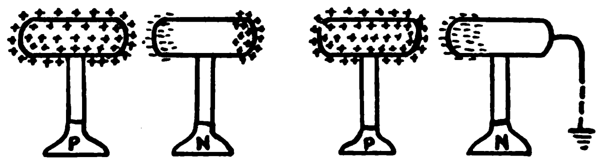
Table II. Conductors and Non-Conductors of Electricity.

Conductors	Specific Gravity	Melting Point °C.
Silver	10.5	960
Copper	8.89	1083
Gold	19.30	1063
Aluminum	2.70	659
Magnesium	1.74	651
Tungsten	19.30	3372
Zinc	7.14	419

Non-Conductors	Kilovolts Per Cm.
Mica	1500 — 2200
Glass	300 — 1500
Ebonite	300 — 1100
Rubber	160 — 500

3. Producing Static Electricity By Induction.—When two metallic bodies, one of which is charged and the other neutral, are brought near together, unlike charges will accumulate on the neutral body at the portion nearest to the charged body; and, like charges will aggregate on the remote side, as shown in Fig. 16a, in which P is charged positively, and N is neutral before it is brought near P. It may be inferred from

this that *"an unlike charge is induced on the side of the body next to the charged body, and a like charge is induced on the remote side of that body."*



(a) (b)

FIG. 16. INDUCTION OF ELECTRIC CHARGES.

According to electron theory, a positively charged body is one with a deficit of electrons, while a negatively charged body contains an excess of electrons. Accordingly, in Fig. 16, while P is near N, and the charges on N are separated, as shown in (a), if a temporary connection is made between N and the ground, for a fraction of a second, as shown in (b), an instantaneous stream of electrons will flow from the ground to N, neutralizing the positive charges on N. As N is withdrawn away from P, the negative charges will spread all over the surface of N, causing it to become negatively charged. Such a process by which substances acquire charges is called *"electrification by induction."*

4. Concentration of Electric Charges At Sharp Points.—It is found in actual practice that when a conductor is charged, those parts of the surface that have the greatest curvatures, or, sharpest points, are charged the most highly. When such a sharp-pointed conductor becomes heavily charged, the excess charges on it are discharged into the surrounding air as fast as they are formed on the point, ionizing, or, charging, the air with the same kind of electricity as that on the conductor. Since like kinds of electricity repel, the charged air is repelled from the point out into space.

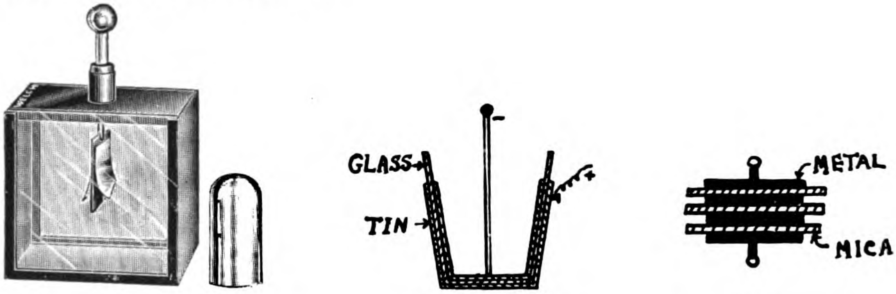
The above phenomenon is utilized in the principle of lightning rod construction. The highest end of the rod is made pointed so as to dispel charges on it as fast as they are formed. The sharp point of the lightning rod being comparatively much higher than any point of the building or the ground on which it is built, draws negative charges, or electrons, from the Earth and charges the neighboring atmosphere with a similar charge. As the now negatively charged air is repelled from the point of the rod, it carries its negative charges to the clouds, which are positively charged on a rainy day, thus neutralizing each other's charges. Therefore, a lightning rod merely functions to prevent the possible formation of a huge amount of charge on the clouds in the neighborhood of the building, and hence, the possibility of the lightning striking the building is obviated.

The reason for the clouds becoming charged positively on a rainy day will be obvious when we consider the clouds as droplets of water, or vapor molecules, polarized and having their heavier charges, or, the positive ions, which constitute the nucleus and most of the extranuclear electrons, located on the portions facing the Earth due to the

force of gravity. Hence, the corresponding negative charges of the vapor particles reside on the remote side of the clouds.

5. The Leyden Jar and The Condenser.—A Leyden jar consists of a cylindrical glass jar lined two-thirds in the inside wall with a layer of tin, or lead foil, and coated on the outside to the same height with the same material.

When the outside coating is connected, for instance, to the positive pole of a source of charge, such as from an electrostatic machine, and the inside foil is connected to the negative terminal, large charges can be rendered both sides of the jar and can be retained on the foils for an appreciable period of time.



(A) THE ELECTROSCOPE. (B) LEYDEN JAR. (C) CONDENSER.
FIG. 17. ILLUSTRATING THE DIELECTRIC EFFECTS OF AIR, GLASS, AND MICA.

To further explain the charging of two metal plates separated by a layer of dielectric material, we shall note that when the outer layer of the glass jar is connected to the positive terminal of the source of charge, it is charged with a positive electricity. Being positively charged, the outer layer, or the tin foil, will attract negative electricity to the inner surface of the glass jar by induction. This will leave the outer surface of the inside foil with an excess of positive charges. Now, if the inner foil is connected to the negative pole of the source of charge, all the excess positive charges on this foil will be neutralized, with the result that the metal foil will become negatively charged. This will tend to draw more positive electricity towards the inner layer, and the outside layer will tend to draw more negative charges towards it, thus producing a strong force of attraction between the charges of the two layers. This process will "condense" the charges on each side of the jar so that relatively a large quantity of static electricity can be stored on each metallic layer of the jar. The glass between the two layers acts as a dielectric, which is an insulator of charges.

The construction of a condenser is based on the principle of the Leyden jar. It is made of alternate layers of metal foil and dielectric. Condensers are widely used in producing high frequency oscillations, filtering rectified currents, in the modulation of radio-frequency waves, etc., both in radio, and medical diathermy apparatus. A condenser may also be used in connection with an impedance circuit to produce amplification of alternating voltages. This is done by charging a number of condensers in parallel and discharging them in series. In some types

of X-ray rectification systems condensers are employed for stepping up the voltage on the secondary side of the X-ray transformer.

6. The Electroscope.—The detection of the presence of a small charge is made possible by the use of a sensitive instrument known as an electroscope, shown in Fig. 17a. The device embodies a cubical metal box having two opposite sides of its walls of glass. At the center of its top piece, the instrument has a metal rod insulated from the box by a collar of amber, or sulphur, and passing into the box chamber it terminates in a flat surface having on each side a gold or aluminum leaf.

When a charged body is brought near the electroscope the leaves will diverge, indicating that charges are induced on the leaves by induction. If the electroscope is charged with one kind of charge, and a like charge is brought near the knob of the instrument, the leaves will diverge still more, while an unlike charge will cause them to collapse.

QUESTIONS ON CHAPTER IV

1. (a) Name five substances that can be electrified by friction.
   (b) Name a liquid that can produce static electricity. State in what trade or enterprise this phenomenon is manifested.
   (c) How many states of static electricity are possible?
   (d) Discuss how static electricity can be utilized.
2. (a) State the law pertaining to electrified bodies.
   (b) What two substances when rubbed together will produce negative electricity on one of them?
   (c) What two substances when rubbed together will produce positive electricity on one of them?
3. (a) What kind or group of substances are good conductors of electricity? Why? Name five of them.
   (b) Name five insulators of electricity.
   (c) Discuss why the charges on a non-conductor do not move from one end of the substance to the other.
4. (a) When two conductors, A and B, are placed near each other but not so near as not to let a spark jump between them, and if A is charged positively, explain what happens to B. Using electron theory, illustrate this effect by diagrams.
   (b) Two conductors, A and B, are placed near together, and A is charged positively. Explain fully how B can be charged with a negative electricity.
5. (a) Give the law of electrostatic induction.
   (b) To what portion of a charged conductor do charges aggregate? Why?
   (c) Explain fully, by electron theory, the function of a lightning rod.
6. Show by a diagram what a Leyden jar is; and, by electron theory, explain how it functions. Name the device that is constructed on the principle of a Leyden jar. State a few uses of this device.
7. What significant place has static electricity in modern times? Discuss some of its uses, and advantages, if any.

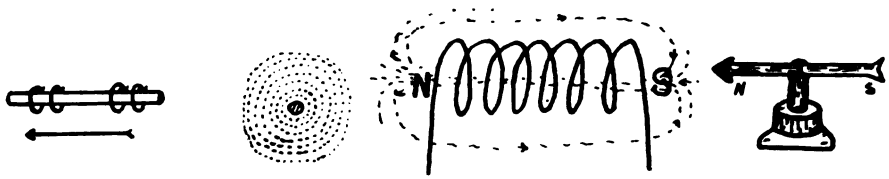
CHAPTER V

ELECTROMAGNETISM

1. Magnetic Field of A Current In A Wire, Coil, or Solenoid.—When current flows through a copper wire, a magnetic field is produced around the wire. The intensity of the magnatic field thus produced varies as the amount of current that is sent through the wire. Doubling the current doubles the strength of the magnetic field, and halving the current halves the strength of this field.

The existence of a magnetic field around a wire carrying current can be demonstrated by the deflection of the compass needle placed near the wire. When the direction of the current is reversed, the deflection of the needle is reversed.

Fig. 18a, below, illustrates the presence of endless lines of force of the magnetic field around a wire carrying current, and Fig. 18b shows the deflection of the compass needle by the magnetic field due to a current passing through the copper coil of wire.



(A) MAGNETIC LINES OF FORCE.

(B) DEFLECTION OF COMPASS BY MAGNETIC FIELD.

FIG. 18. MAGNETIC FIELD DUE TO A CURRENT FLOWING IN A CONDUCTOR.

The application of this phenomenon in the manufacture of giant power generators, induction motors, telephones, telegraphs, radio circuits, doorbells, etc., has rapidly grown into the modern trend of vast electrical industry. Some of the greatest water falls, or waters in dams, are harnessed to operate plants generating electromagnetic fields, and hence electric power, which is transmitted over copper wires to be utilized as light, heat, or mechanical power, in cities, or towns.

Fig. 19 represents a solenoid consisting of a coil of insulated copper wire having a soft iron bar inserted through it to constitute a magnetic core. When a current flows in the coil, magnetic lines of force are produced, which, in turn, will magnetize the iron core by induction. The iron magnet thus produced will add its magnetic field to the current-magnetic field of the coil, with the result that a strong magnetic field will be produced throughout the solenoid. Such a solenoid is also called an electromagnet.

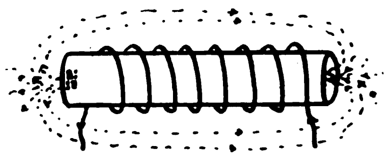


FIG. 19. MAGNETIC FIELD PRODUCED BY A SOLENOID.

2. The Right-Hand Rule For Current-Magnetic Fields.—In order to determine the direction of the magnetic field induced around a wire carrying current, the wire must be grasped (in a figurative sense) with the right hand, the fingers lying around the wire and the thumb pointing in the direction of the current flow. When such a position is assumed, as shown in Fig. 20, the fingers around the wire will follow the lines of current-magnetic force thus induced.

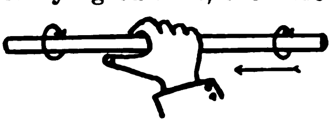
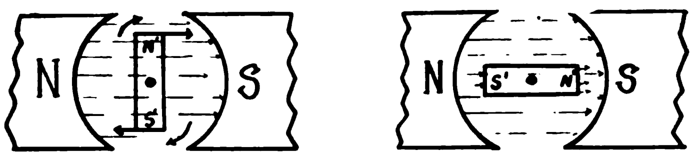


FIG. 20. INDUCED MAGNETIC FIELD AROUND A WIRE.

3. The Torque In A Magnetic Field.—Previously it was mentioned that like magnetic poles repel and unlike attract. Therefore, if a bar magnet is placed intermediate to two magnetic poles, as shown in the accompanying Fig. 21a, the magnetic bar will tend to rotate so as its magnetic field lies parallel with the field of the other poles, and it will come to a rest in a position as shown in Fig. 21b, in which unlike poles are attracted to each other. The bar magnet is thus said to have made a rotation of 90 degrees.

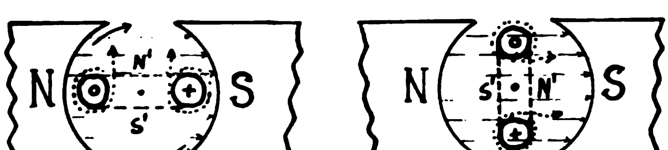


(A) MAGNETIC FORCE AT RIGHT ANGLES TO THE FIELD.

(B) MAGNETIC FORCE PARALLEL TO THE DIRECTION OF FIELD FORCE.

FIG. 21. ROTATION OF A MAGNET IN A MAGNETIC FIELD.

Similarly, when a coil of wire carrying current is placed in a magnetic field, as in Fig. 22a, the coil behaves as if it were a magnet, since the current has induced a magnetic field around it. When two imaginary parallel lines are drawn on the peripheral plane of the coil, one surface of the plane may be regarded as the north pole, marked by N′, and the other as south pole, marked by S′, of a magnet of same size and shape as the coil.



(A) LINES OF FORCE OF COIL AT RIGHT ANGLES TO MAGNETIC FIELD

(B) LINES OF FORCE OF COIL PARALLEL TO THE MAGNETIC FIELD

FIG. 22. A COIL OF WIRE IN A MAGNETIC FIELD.

Moreover, since like magnetic forces repel and unlike attract, the rotational forces acting on the coil will be in the direction of the solid line arrows. The coil will rotate so as its lines of force will lie parallel with

the magnetic field of the iron poles as shown in Fig. 22b.

The force acting to rotate the coil of wire in Fig. 22a will be same as that of the magnetic bar shown in Fig. 21a, provided that the magnetic field strength of both the bar magnet and the "coil magnet" are same. Therefore, the force with which the magnet, or, the "magnetic coil", will rotate is known as the magnetic *torque.* The forces on each pole of a magnet are equal, hence the forces on each coil side of the "magnetic coil" are equal. Putting this in a general rule form: *The magnetic torque is equal to the product of the strength of one of the poles of the magnet times the field strength and the length of the magnet.*

The equation for the magnetic torque is given as:

$$T = gHL \qquad (7)$$

where, T = Torque in dyne-cms.
H = Field intensity in gilberts, or gausses.
g = Pole strength in gauss.
L = Length of magnet in cms.

Example:—A magnet having a pole strength of 4500 gausses is placed at right angles to a magnetic field of an intensity 9800 gilberts. If the length of the magnet is 24 cms., what will be the torque?

$$T = gHL$$

where, g = 4500 gausses.
H = 9800 gilberts.
L = 24 centimeters.

$$T = 4500 \times 9800 \times 24 = 1{,}058{,}400{,}000 \text{ dyne-cms.} \quad \textit{Ans.}$$

Since one gram weight is equal to 981 dynes, the torque may also be given as gram-centimeters.

Thus, $$T = \frac{1{,}058{,}400{,}000}{981} = 1{,}078{,}899.0 \text{ Gm-cms.} \quad \textit{Ans.}$$

The force exerted on a single coil of wire carrying current and placed in a magnetic field is directly proportional to the field intensity, or, the flux density, the current through the coil, and the axial length of the coil exposed to the magnetic field. Thus, the formula is

$$F = \frac{BIL}{10} \text{ dynes.} \qquad (8)$$

For a coil consisting of N turns of wire, the formula becomes

$$F = \frac{BLNI}{10} \text{ dynes.} \qquad (9)$$

Examples:—(a) A coil of wire carrying a current of 2 amperes is placed in a magnetic field whose intensity is 490 gausses. If the axial length of the coil is exposed to the magnetic field is 8 cms., and its radius is 6 cms.,

what will be the torque in gram-centimeters?

In the problem are given:

$B = 490$ gausses.
$r =$ Radius, 6 cms.
$L =$ Axial Length, 8 cms.
$I = 2$ amperes.

Thus,
$$F=\frac{BIL}{10}=\frac{490\times2\times8}{10}=784 \text{ dynes}$$

and, since Torque = Force x Distance between coil sides, we have,
$$T = F \times 2r = 784 \times 2 \times 6 = 9408 \text{ dyne-cms.}$$

$$T=\frac{9408}{981}=9.58 \text{ gram-cms.} \quad \textit{Ans.}$$

If there were, for instance, 200 coils instead of one coil, the Torque would be 9.58 x 200 = 1916 gm-cms.

(b) A motor has 300 windings around its armature. The axial length of each coil exposed to the field flux is 12 cms., and the current through the coil is 3 amperes. The radius of the armature from the center of the shaft to the center of the coil is 6 cms. What will be the torque in Kgm-meters, if the air-gap flux density is 49,050 gausses? The permeability of the armature is neglected. (1 Kgm = 1000 grams, and is also equal to 981,000 dynes.)

In the problem are given:

$N = 300$ turns of wire.
$L = 12$ cms.
$I = 3$ amperes.
$r = 6$ cms.
$B = 49{,}050$ gausses.

$$\text{Force on each coil} = \frac{BIL}{10} = \frac{49{,}050\times3\times12}{10} = 176{,}580 \text{ dynes}$$

$$\text{Force on 300 coils} = 176{,}580 \times 300 = 52{,}974{,}000 \text{ dynes.}$$

and,
$$\begin{aligned}\text{Torque} &= F \times 2r\\ &= 52{,}974{,}000 \times 2 \times 6\\ &= 635{,}688{,}000 \text{ dyne-cms.}\\ &= \frac{635{,}688{,}000}{981{,}000} = 648 \text{ Kgm-cms.}\\ &= \frac{648}{100} = 6.48 \text{ Kgm-meters.} \quad \textit{Ans}\end{aligned}$$

4. The Electric Motor.—**An electric motor is a device which converts an electrical energy into mechanical energy. That is, a motor functions by consuming current or electricity, which, by virtue of its producing**

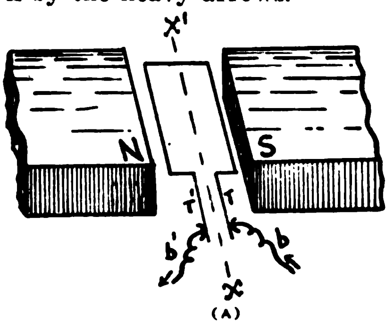
magnetic rotational forces, causes the shaft of the motor to rotate. When this rotating shaft is connected to other systems by pulleys, or gears, a mechanical power can be produced. Street cars, electric railways, elevators, vacuum pumps, grinding machines, majority of machinery in factories, and a variety of the tools of the artisan are operated by means of a motor.

The motor consists of an iron armature, around which are wound many turns of coarse insulated copper wire. The armature is placed between two or more magnetic poles having coils of copper wire wound around them. The same current, passing through the armature coils simultaneously, excites the armature by producing magnetic rotational forces about these coils.

When a current is sent through the armature coils, which are placed in the magnetic field of the poles, the coils will behave as magnets, and thus forces will act on the armature tending to rotate it, as like magnetic fields repel and unlike attract. This principle is closely adhered in building induction motors which are operated solely by the attraction and repulsion of magnetic fields produced by multiple phase alternating currents.

In the accompanying Fig. 23a is shown diagrammatically an isolated armature coil mounted on an imaginary axis x - x′. The coil is placed in the magnetic field of the poles of a motor. If the terminals *t* and *t′* of the coil slide over the two contact points, or the brushes, of the circuit, as marked by *b* and *b′*, and the current enters the coil at *t* and leaves at *t′*, lines of magnetic force will be induced around the coil. On the side of the coil next to the magnetic north pole forces will act upward, and on the side next to the south pole forces will act to push the coil downward. These forces being equal but opposite in direction will form a couple, and the coil will rotate clockwise.

Fig. 23b represents the cross-section of the coil shown in Fig. 23a. As current enters at *t* and leaves at *t′*, the magnetic lines of force thus produced on the coil sides are marked by the broken arrows. The coil now can be considered as a magnet of same size and shape with a south magnetic plane, marked by *S′*, and a north magnetic plane, marked by *N′*. Since unlike poles attract and like poles repel, the plane *N′*, will be attracted to the south pole, and the plane *S′* to the north pole of the field magnet, with the result that the coil will rotate between the poles as shown by the heavy arrows.



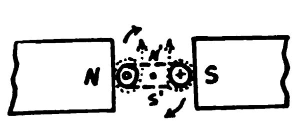


FIG. 23. A COIL CARRYING CURRENT AND PLACED IN A MAGNETIC FIELD.

When the coil rotates through an angle of 90 degrees from the position shown in Fig. 23b, it will cease to rotate, as its magnetic field in the latter position will lie parallel to the field of the poles. Therefore, in order to secure a continuous rotation, a plurality of coils, with their planes inclined to each other, are wound around the armature. The terminals of each coil function individually as the contact points to the incoming current. Such an arrangement constitutes a direct-current motor. A diagrammatic representation of a direct-current motor is shown in the accompanying Fig. 24.

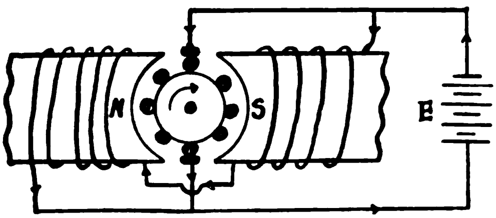


FIG. 24. A DIRECT-CURRENT MOTOR.

(a) The field intensity produced at the pole face of the motor is given as

$$B=\frac{4\pi NI}{10L} \text{ gausses.} \tag{10}$$

where, B is the flux density, N the number of turns on each pair of poles, I is the current in amperes, and L is the air-gap distance (distance between the pole face and the armature surface) in cms. Equation (10) may also be written as

$$BL=.4\pi NI \text{ dynes.} \tag{11}$$

But,

$$BL=F \quad \text{where, } F=\text{Magnetomotive force in dynes.}$$

and,

$$F=.4\pi NI \text{ dynes.} \tag{12}$$

(b) The ampere-turns for a single air-gap may be derived from equation (10), or (11).

Hence,

$$BL=.4\pi NI$$

and,

$$NI=\frac{BL}{.4\pi}=\frac{BL}{.4\times 3.1416}$$

$$NI=BL\times\frac{1}{1.256}$$

$$NI=.796\ BL \text{ (ampere-turns)} \tag{13}$$

Example:—A motor has a pole face area of 400 sq. cms., and an air-gap distance of 0.20 cms. If the pole strength is 36,000,000 maxwells in total, determine NI to produce this flux at the pole face, the permea-

bility of iron being neglected.

$$NI = .796 \times B \times L$$

where, $B = \dfrac{\phi}{A} = \dfrac{36{,}000{,}000}{400}$

$= 9000$ gausses.

$L = 0.20$ cms.

therefore,

$$NI = .796 \times 9000 \times 0.20$$

$$= 1432.8 \text{ ampere-turns.} \qquad \textit{Ans.}$$

If 4 amperes were running through the coils of the field poles, then approximately 358 turns of wire would be necessary to produce the above given flux.

The power output of a motor is expressed in horse-power, which is dependent upon the speed, and the torque of the armature. Expressed in an equation form

$$\text{Power Output} = \frac{2\pi NT}{33{,}000} \text{ Horse-Power.} \tag{14}$$

where, N is the number of rotations per minute, and T is the torque in gram-cms.

5. The Electric Generator.—An electric generator is a device that converts mechanical energy into an electrical energy. That is, when the armature of a generator is rotated by means of a pully connected to an external source of rotating system, such as a wind-wheel, or a water-powered wheel, the rotational force is expended in producing large magnetic fields, which, in turn, are transformed into electric current and potential. Fig. 24, below, represents a schematic diagram of a generator.

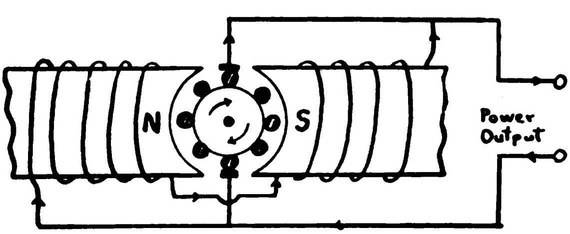


FIG. 25. A DIRECT-CURRENT GENERATOR.

The equation for the potential, or electromotive force, produced by a direct-current generator is given as

$$E = \frac{2PZ\phi N}{60p} 10^{-8} \text{ volts.} \tag{15}$$

where,
P = Number of pairs of poles.
Z = Total number of conductors in armature winding.
ϕ = Flux per pole.
p = Number of parallel magnetic circuits through the armature.
N = Number of revolutions per minute.

QUESTIONS ON CHAPTER V

1. (a) What phenomenon takes place around a conductor carrying a current? Explain how it can be detected.
   (b) In what fields of industry the application of this phenomenon is expedited?
   (c) Discuss the direction of the magnetic field in a solenoid carrying a current.
   (d) State the right-hand rule for induced magnetic fields.

2. (a) Explain fully the torque produced in a magnetic field.
   (b) Define magnetic torque, and give the formula.
   (c) A magnet has a pole strength of 3000 gausses, and is placed at right angles in a magnetic field of an intensity of 12,000 gilberts. If the length of the magnet is 18 cms., what will be the torque in gram-cms?

3. (a) Give the formula for the rotational force acting on a coil of wire carrying a current and placed in a magnetic field at right angles.
   (b) A coil of 200 turns carrying a current of 1.2 amperes is placed in a magnetic field whose intensity is 360 gausses. If the axial length of the coil exposed to the magnetic field is 6 cms. and its radius 3.6 cms., (1) What will be the force in dynes? (2) what will be the torque in gm-cms.?

4. (a) What is a motor? A generator? Discuss their uses.
   (b) Explain by diagrams how the armature of a motor operates.
   (c) Give the formula for the field intensity produced at the pole face (air-gap) of a motor.

5. (a) What is a magnetomotive force? Give the formula.
   (b) Derive the formula for the ampere-turns for a single air-gap.
   (c) Explain fully how a simple two-pole motor functions.
   (d) Give the formula for the electromotive force produced in a direct-current generator.

6. A current of 10 amperes is running in a certain dynamo which produces a magnetomotive force of 5000 dynes, and has an air-gap distance of 0.20 cm.
   (1) What is the flux density through the armature?
   (2) What should be the number of turns around the poles to produce this flux?
   (3) If the armature has a diameter of 12 cms., what will be the torque in gm-cms.?
   (4) What is the total flux at each pole face, if the latter has an area of 8x10 cms.?
   (5) What horse power will this dynamo produce if the armature rotates 1800 times per minute?

CHAPTER VI

ELECTRODYNAMICS

1. A Consideration Of Dynamic Currents.—A dynamic current is electricity in motion, in which case, electrons, instead of remaining stationary as in the case of static electricity, flow from one end of the conductor to the other, producing an electric current.

In considering the cases of flow of electricity through conductors (wires), it is essential to account for the fundamental electrical units which directly enter into the generation, conduction, and consumption of electrical power in the form of light, as in electric lamps, or in the form of heat, as in the case of electric heaters and ovens.

When electricity is generated at the power plant by huge water-powered generators, what really takes place is a dissociation of electrons. But, unless there is also an electrical pressure behind these electrons, no current will flow to an external circuit. Therefore, in order to produce a flow of current or electrons in a wire, a generator should poduce an electrical pressure as well as current. Such is the case, for when current is produced in a generator, simultaneously an electrical pressure or, more technically termed, an electrical potential, sufficiently great to drive the current through conductors exterior of the generator is also produced, and a continuous flow of current is thus the result.

As the current leaves the power house and before it reaches the city, a certain amount of the current is dissipated during its flow through the transmission wires. This loss is due to the presence of a certain amount of electrical resistance in the wires against the flow of the current. Therefore, some of the current is used up through overcoming this resistance. Such a loss generally occurs in the form of an evolution of heat from the wires transmitting the current.

2. The Electrical Units of Measurement.—The electrical factors that enter into the generation and transmission of a current are the Voltage, Amperage, and the Ohmage. The Voltage is the electrical force, or potential, behind the flow of current which is known as the Amperage. The electrical resistance offered to the passage of current in a conductor is called the Ohmage of that conductor.

All the above relations collectively make up the Wattage, which is the total electrical energy generated, or total electrical work done by the combined functioning of all the three quantities.

The practical units in electricity are:

1 Volt	=A Unit of Voltage, or Potential.
1 Ampere	=A Unit of Amperage, or Current.
1 Ohm	=A Unit of Ohmage, or Resistance.
1 Watt	=A Unit of Wattage, or Power.

Definitions Of Electrical Units.—

(a) *Coloumb*: A coulomb is the quantity of charge carried by a current of 1 ampere for 1 second. $Q = It$, equation (3).

(b) *Ampere*: An ampere is the amount of current carried by an electrical potential of 1 volt through a conductor having a resistance of 1 ohm. Or, an ampere is the amount of current which when passed through a solution of Silver Nitrate will deposit Silver at the rate of 1.118 milligrams per second.

(c) *Volt*: A volt is the unit electrical potential to overcome a resistance of 1 ohm in a conductor carrying a current of 1 ampere.

(d) *Ohm*: An ohm is the unit resistance to be overcome by a potential of 1 volt in driving a current of 1 ampere through a conductor.

(e) *Watt*: A watt is the unit rate of electrical power generation, or, consumption. It is the work done by 1 volt in driving a current of 1 ampere in one second.

Since we shall have further occasion to deal with these electrical quantities, it is essential that the student has a thorough understanding before proceeding any further.

3. Fall of Potential — Ohm's Law.—As mentioned before, when current flows in a conductor, there is always a certain amount of drop in the voltage of the transmitting circuit. This is due to the resistance of the conductor. The higher the resistance of the conducting circuit, the higher the voltage drop in the circuit. To compute this fall of potential in an electric circuit, Ohm has formulated the following relations between the electrical units:

(a) When current is transmitted through a conductor, the current of transmission varies directly as the electromotive force (voltage) and inversely as the resistance (ohmage) of the transmitting circuit.

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Resistance}}$$

$$I = \frac{V}{R} \tag{16}$$

where, I is the current in amperes, V the electromotive force in volts, and R is the resistance in ohms.

(b) The fall of potential in a portion of an electrical circuit is equal to the current times the resistance of that portion.

Fall of Potential = Current x Resistance

$$V = I \times R \tag{17}$$

and,

$$R = \frac{V}{I} \tag{18}$$

Example:—A house 2 miles from the power house uses a current of 2.5 amperes in an electric heater, and 0.80 ampere in an electric lamp. **(a)**

What will be the potential drop in the transmission lines, if there is a resistance of 0.20 ohm per 1056 feet of the copper wire? (b) What will be the potential drop at the electric heater if it has a resistance of 20 ohms?

In the (a) part of the problem, we are given

$$V' = IR \quad \text{equation (17).} \qquad \begin{aligned} V' &= \text{Potential drop in line.} \\ I &= 2.5 + .80 = 3.3 \text{ amperes} \\ R &= 2 \text{ ohms in 2 miles} \\ &= 4 \text{ ohms in both wires.} \end{aligned}$$

$$\begin{aligned} V' &= 3.3 \times 4 \\ &= 13.2 \text{ volts.} \quad \textit{Ans.} \end{aligned}$$

In the (b) part of the example, we are given

$$\begin{aligned} V'' &= \text{Potential drop in heater.} \\ I &= 2.5 \text{ amperes.} \\ R &= 20 \text{ ohms.} \end{aligned}$$

From equation (17), we have

$$\begin{aligned} V'' &= IR \text{ volts.} \\ V'' &= 2.5 \times 20 = 50 \text{ volts.} \quad \textit{Ans.} \end{aligned}$$

4. The Electric Power — Wattage.—In electricity, power is defined as the rate of doing electrical work. The work is given as the product of the current times the voltage and the time the current is prolonged. The unit of electric power is the watt, and the electrical work done in one second is known as one watt-second or one joule. Since power is only the rate of doing work, it follows that work per second is the power, or the number of watts used.

It is common practice to rate the different electric appliances according to the amount of wattage used. For example, an incandescent lamp rated as 60-watts, at 110 volts, signifies that when this lamp is connected across a circuit of potential difference 110 volts, it will consume 60 watts of power per second. Electric motors, heaters, ovens, fuses, etc., are all rated by the amount of power in watts used under specified voltage conditions.

The relation of electrical work to practical units is

$$\text{Electrical Work} = \text{Amperes} \times \text{Volts} \times \text{Seconds}$$

or,

$$W = I \times V \times t \text{ (watt-seconds)} \tag{19}$$

Example:—A current of 2 amperes at 110 volts runs in a circuit for 20 minutes. What is the electrical work done in joules?

$$\text{We are given:} \quad \begin{aligned} I &= 2 \text{ amperes.} \\ V &= 110 \text{ volts.} \\ t &= 1200 \text{ seconds.} \end{aligned}$$

$$\begin{aligned} W &= I \times V \times t \quad \text{(equation 19)} \\ W &= 2 \times 110 \times 1200 = 264{,}000 \text{ joules.} \quad \textit{Ans.} \end{aligned}$$

The power transmission, or consumption, is given in watts, for which the formula is

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{joules}}{\text{seconds}} = \text{Amperes} \times \text{Volts} = \text{Watts}$$

or,

$$P = \frac{I \times V \times t}{t} = I \times V$$

$$P = IV \text{ watts.} \qquad (20)$$

where, P is the power in watts.

The equation (20) may be expressed in the following form:

$$P = \frac{V^2}{R} \text{ watts.} \qquad (21)$$

Example:—If an electric toaster is using a current of 3 amperes at 60 volts, (a) what power is delivered to the toaster? (b) What is the resistance of the toaster?

(a) $P = I \times V$ where, $I = 3$ amperes. $V = 60$ volts.

$P = 3 \times 60$
$= 180$ watts. *Ans.*

(b) From equation (21), we have $P = \frac{V^2}{R}$; or, $R = \frac{V^2}{P}$

then, $R = \frac{V^2}{P}$ where, $V = 60$ volts. $P = 180$ watts.

and, $R = \frac{(60)^2}{180}$

$= \frac{3600}{180} = 20$ ohms. *Ans.*

It is further noticed that the resistance in the (b) part of the example may be determined by using the equation (18), which gives

$R = \frac{V}{I}$ where, $V = 60$ volts. $I = 3$ amperes.

$R = \frac{60}{3} = 20$ Ohms. *Ans.*

It is also well worth mentioning that the following relations in expressing the power consumption in a circuit also exist:

Electrical Work:—

Electrical Work, Watt-Seconds = Joules = $I \times V \times t$
Electrical Work, Watt-Minutes = Watts × Minutes.
Electrical Work, Watt-Hours = Watts × Hours.

$$\text{Electrical Work, Kilowatt-Hour} = \frac{\text{Watts} \times \text{Hours}}{1000}$$

1 Horse-Power = 746 Watts.

Example:—How much will it cost to run an electric pressing machine for half an hour, if the meter rating is 10 cents per kilowatt-hour, and if the machine uses 1.5 horse-power of current?

$$1.5 \text{ H.P.} = 746 \times 1.5 = 1119 \text{ watts}$$

For half an hour, it will take

$$1119 \times .5 = 559.5 \text{ watt-hours.}$$

or,

$$= \frac{559.5}{1000} = .5595 \text{ Kilowatt-Hour.}$$

At 10 cents per KW-HR., this will cost

$$.5595 \times 10 = 5.6 \text{ cents.} \qquad \textit{Ans.}$$

5. Joule's Law.—When current is sent through a conductor heat is developed, the amount of the latter depending on the magnitude of the current and the resistance of the conductor. Joule, an early investigator, discovered that the heat energy developed by a current running through a conductor is proportional to the square of the magnitude of the current, the resistance of the conductor, and the time of current flow. The unit work producing this heat energy is called a *joule,* after the discoverer of the phenomenon.

Heat Energy in Joules = (Current)^2 x Resistance x Time

$$\text{Joules} = I^2Rt \tag{22}$$

where, I is the current in amperes, R the resistance of the conductor, and t is the time in seconds the current is prolonged.

The heat energy is measured in gram-calories. A *calorie* of heat is the work done by 4.19 joules, or by 4.19 watts in one second.

$$\text{Heat Energy} = \frac{I^2Rt}{4.19} \text{ calories.} \tag{23}$$

or,

$$\text{Heat Energy} = .24I^2Rt \text{ calories.} \tag{24}$$

In computing for power loss, or, power consumption, in a wire having a resistance R, and a current of I flowing through the circuit, we have the relation

$$P=I^2R \text{ watts.} \tag{25}$$

The equation (25) is always used in finding the power consumption in any system containing pure resistance and thus producing heat. For example, electric heaters, incandescent lamps, electric ovens, etc., all produce heat. Therefore, the formula (25) is applied in the determination of the total energy used both in a direct-current, and alternating-current circuits. The formula, $P = I \times V$, however, may be used alternatively with equation (25) in cases where direct-current is used.

***Example*:**—A coil of wire having a resistance of 10 ohms carries a current of 2 amperes for 20 minutes. (a) What will be the heat generated in calories?

$$\text{Heat units, } C=.24I^2Rt \text{ calories.}$$

$$\text{where, } \begin{aligned} I&=2 \text{ amperes.}\\ R&=10 \text{ ohms.}\\ t&=1200 \text{ seconds.}\\ C&=\text{Calories.}\end{aligned}$$

$$C = .24 \times 4 \times 10 \times 1200 = 11{,}520 \text{ Calories. Ans.}$$

(b) If all the heat thus produced is used up to warm 500 Cc of water, initially at 20 degrees C., what will be the final temperature of the water?

At 20°C, 500 Cc of water has 10,000 calories.

$$10{,}000 + 11{,}520 = 21{,}520 \text{ Calories in total.}$$

Since the volume of water is 500 Cc, the final temperature will be

$$21{,}520 \div 500 = 43.04°\text{C. Ans.}$$

(c) How much will it cost to heat 100 gallons of water for 40 hours, if power is supplied at 5 cents per *KW-Hr?*

$$\text{We are given: } \begin{aligned} I&=2 \text{ amperes.}\\ R&=10 \text{ ohms.}\\ H&=40 \text{ hours.}\end{aligned}$$

$$\text{KW-Hr}=\frac{I^2RH}{1000}$$

$$=\frac{4\times10\times40}{1000}=1.6 \text{ KW-Hrs.}$$

At 5 cents per *KW-Hr.*, the power cost will be:

$$5\times1.6=8 \text{ cents.} \qquad \textit{Ans.}$$

6. The Heating Effects of Electricity.—The heating effects of an electric current are manifested in the incandescent lamps, electric toasters, pressing irons, electric heaters, fuses, and a number of other household appliances.

In order to produce heat from electric currents, coils of wire which offer some resistance to the flow of current are used. Different metallic substances have different and specific resistances per given length and diameter. There are on the market many types of coils that are well-suited for heating purposes. Chromel, Nichrome, Nickel-Chromium alloys, Tungsten, Tungsten-Osmium alloys, etc., are sold on the market in wire or ribbon forms. These can be used in almost any device for producing heat by the use of electric currents. At present, Tungsten-Osmium alloys are employed in the filaments of incandescent lamps, Nichrome in heater units, and Tungsten is generally used in the cathode filaments of rectifiers, X-ray tubes, and radio tubes.

The melting of certain soft metals under electric currents is utilized in constructing electric fuses. Fuses are safety devices used in electric circuits for breaking the circuit, by virtue of their low melting-points, when the current becomes abnormally greater than the fuse is rated to carry. Ordinarily, a fuse link is made of an alloy of Lead and Tin, or of pure Zinc, Aluminum, etc., any of which melts at a low temperature. The link is enclosed in a cartridge or in a plug receptacle which is screwed in a socket in the fuse box provided for this purpose. Fuses are connected between the power line and the house-hold circuit.

When metals of high melting-point are heated to incandescence they emit light. The higher the temperature of the body the greater is the percentage of light radiation. Generally, an incandescent body in air oxidizes quite rapidly, thus becoming useless in course of time. When the incandescence of a metal takes place in vacuum, the life of the metal is considerably increased. An example of this is the electric lamp, whose filament is heated to an incandescence in an evacuated glass bulb. However, it is found that after the bulbs are evacuated and filled with an inert gas, such as Argon, or Nitrogen, at low pressures, the vaporization of the metallic filament under heat of incandescence is greatly reduced, and the efficiency of the lamp is markedly improved.

7. Loss of Electric Power Along Transmission Lines.—The lines transmitting the current from a power house to the city have certain amount of electrical resistance in them. Wires of different materials offer different electrical resistances to the flow of current through them. Copper wire, having comparatively less resistance than any other metal sufficiently inexpensive to be commercially practicable is advantageously suited for the transmission of electricity.

The power loss in the wire varies with the size of the copper—the larger the diameter the less power is lost during transmission. But, the weight of such large size, or, large diameter, wires is so great and the cost of material and installation so high that it will be almost prohibitive and very impractical to convey power very far from the power house. To overcome this disadvantage, copper-wires of smaller diameters are used for the transmission of power to long distances.

By using a wire of small diameter, naturally one would expect an increased resistance in the circuit, and a certain quantity of power loss in the form of heat during transmission. In such a case, the power loss, I^2R, will depend on the magnitude of the current during transmission, since the resistance along the lines is uniformly constant. Therefore, the

greater the current of transmission, the higher is the power loss. This fact is further elucidated in the following example:

Example:—A two-wire transmission line, 4 miles long, of copper wire having a resistance of 0.20 ohm per mile of wire, carries a current of 100 amperes at 220 volts. What will be the power loss during the transmission of this current?

$$\text{We are given:}\quad \begin{aligned} I &= 100 \text{ amperes.}\\ V &= 220 \text{ volts.}\\ R &= 1.6 \text{ ohms.}\end{aligned}$$

$$\text{Power Loss} = I^2R = (100)^2 \times 1.6 = 16{,}000 \text{ watts.} \qquad \textit{Ans.}$$

The power from the power house, however, is 100 x 220 = 22,000 watts. Hence, the useful energy reaching the city will be

$$22{,}000 - 16{,}000 = 6{,}000 \text{ watts.}$$

Therefore, power transmitted at low voltage and high amperage is very impractical, since there is a considerable amount of power loss during the transmission. As illustrated in the above example, over 70% of the power is lost during transmission. The cost of carrying power at such a low efficency is prohibitive.

But, suppose the electricity is transmitted at a high voltage and low amperage, it will be readily seen that the power loss due to I^2R will be greatly reduced, becoming almost negligible, as will be shown in the following illustration:

Example:—Suppose in the preceding problem, the power was transmitted at 2,200 volts and at 10 amperes. What would be the power loss during transmission?

$$\text{We are given:}\quad \begin{aligned} I &= 10 \text{ amperes.}\\ V &= 2{,}200 \text{ volts.}\\ R &= 1.6 \text{ ohms.}\end{aligned}$$

$$\begin{aligned}\text{Power Loss} &= I^2R\\ &= (10)^2 \times 1.6\\ &= 100 \times 1.6 = 160 \text{ watts.} \qquad \textit{Ans.}\end{aligned}$$

It is obvious that 160 watts as compared with 16,000 watts loss is a negligible amount. The power transmission efficiency in this case is increased a hundred times. Owing to this fact that power is generally transmitted to long distances along high tension (high voltage) lines at a comparatively low amperage.

QUESTIONS ON CHAPTER VI

1. (a) What is a dynamic current? Discuss its generation and transmission.
   (b) How do the electrical factors enter into the generation and transmission of electricity?
   (c) Define: Coulomb, ampere, volt, ohm, watt, milliampere, and kilovolt.
2. (a) State Ohm's two laws, and give the formula for each.
   (b) Account for the voltage drop in a conductor.
   (c) An electric heater having a resistance of 20 ohms uses a current of 6 amperes.

What is the potential drop across the heater?

3. (a) A current of 4 amperes at 120 volts is running through a heater element. (1) What is the resistance of the heater element? (2) What power is expended in the circuit?
   (b) Define:—Power, work in joules, heat energy in joules, watt, watt-second, watt-minute, watt-hour, and horse-power.
   (c) Discuss the significance of I^2R, and its application.

4. (a) Two horse-power of electrical energy is used for five minutes in carrying 5 tons of coal to a distance of one mile. (1) What power is used in watt-minutes? (2) What will be the work in joules? (3) How many calories are expended if all the power is transformed into heat?
   (b) Discuss the heating effects of electric power.

5. (a) Explain fully, what factors enter into the production of heat from electric energy.
   (b) Explain and illustrate with a problem why electrical energy is transmitted at high tension.
   (c) An electric percolator, having a resistance of 15 ohms, carries a current of 2.5 amperes for 20 minutes. (1) What will be the heat generated in calories? (2) If all the heat were used to heat one liter of water, initially at 15 degrees centigrade, what would be the final temperature of the water?

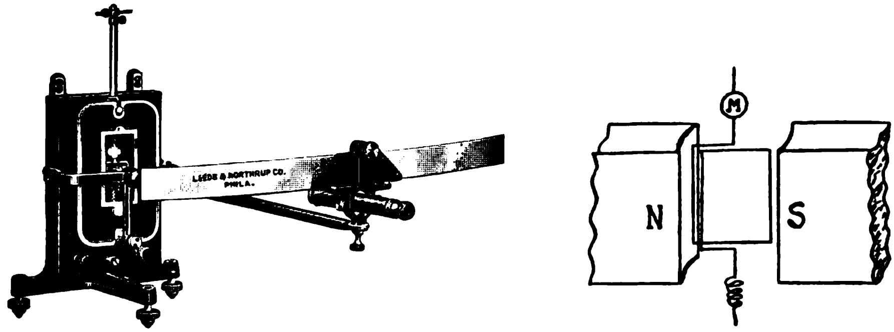
6. (a) A current of 250 milliamperes is sent through a circuit having a resistance of 10,000 ohms. (1) What is the potential drop in the circuit? (2) How much power is used in the circuit?
   (b) A power of 20 Kilowatts is transmitted over a double transmission line having a resistance of .20 ohm per mile of wire to a distance of 4 miles. If the current in the transmission is 1 ampere, (1) What is the potential drop in the line? (2) What was the initial voltage at the source of transmission?

CHAPTER VII

ELECTRICAL MEASUREMENTS

1. Electric Measuring Meters.—The principle of the induction of magnetic lines of force about a coil of wire carrying a current is used in the construction of instruments for measuring the quantity, or, quality, of a current in a circuit. Such devices primarily consist of a coil of wire, free to rotate on its axis, and conveniently supported in a magnetic field. The rotation, or, the deflection, of the coil is dependent upon the magnitude of the current through it. By attaching a pointer to the shaft of the moving coil, and having a calibrated scale arrangement on the face of the instrument, the deflection of the pointer accurately determines the quality of the current passing through the meter.

(a) *The D'Arsonval Galvanometer*:—One of the simplest and most sensitive electric measuring devices is the D'Arsonval galvanometer, Fig. 26, which consists of a moving coil suspended between two poles of a strong horse-shoe magnet. The suspensions above and below the coil constitute the leads for the incoming and outgoing current through the instrument. A mirror, M, connected to the upper suspension, rotates with the coil in accordance with the magnitude of the current flowing through the coil. The deflection of the coil is directly proportional to the amount of current, or, charge. Therefore, by means of a scale and telescope arrangement, readings are conveniently taken.

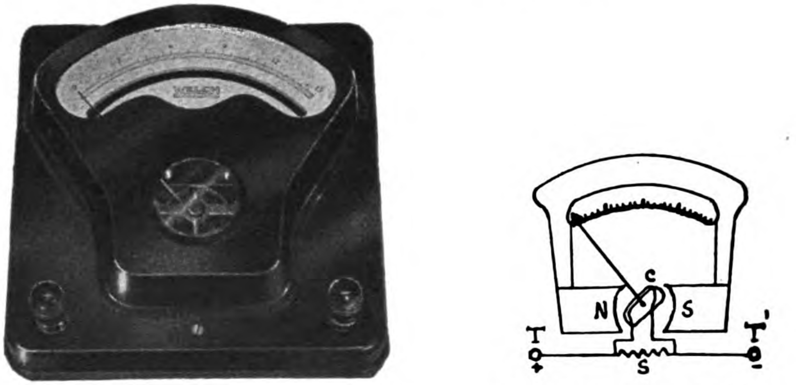


(A) THE BALLISTIC GALVANOMETER (B) CIRCUIT DIAGRAM OF THE INSTRUMENT.

FIG. 26. THE D'ARSONAL GALVANOMETER.

The sensitivity (response to very small currents, or potentials) of a galvanometer varies from 10^{-3} to 10^{-9} ampere per millimeter of scale deflection. This makes the instrument very valuable in the accurate measurement of resistances of different conductors, and some types of insulators. A very elegant method of employing the galvanometer is in measurement of resistances by Wheatstone bridge circuit, while Kelvin double-bridge method is essentially an improvement on the former.

(b) *The Ammeter*:—An ammeter is a portable galvanometer of modified form, and measures the current in amperes. It is provided with a moving coil mounted in jewel bearings balanced with coil springs from either side. A pointer, mounted on the coil, is actuated by the deflection of the coil, indicating on a scale arrangement the amount of current passing through the meter. Fig. 27a represents a commercial form of an ammeter, while Fig. 27b is a schematic diagram of the ammeter.



(A) A COMMERCIAL FORM OF THE AMMETER.

(B) THE SCHEMATIC DIAGRAM OF THE AMMETER.

FIG. 27. THE DIRECT-CURRENT AMMETER.

In Fig. 27 (b), the moving coil C of the instrument is mounted between the two poles, marked by N and S, of a permanent magnet. A shunt S is connected across the coil and carries most of the current, which flows through the binding posts T and T′. Since the resistance of the coil C is much higher than the shunt resistance the current passing through the former is comparatively very small.

The inclusion of a shunt in an ammeter is very essential, since the moving coil is too delicate to permit a large current through the instrument. The current that flows in the coil, however, is proportional to the total current of the circuit, and varies as the ratio of the resistances between the moving coil and the shunt. That is, if it is desired that an ammeter read 10 amperes at full-scale deflection, the respective coil and shunt resistances must be so chosen that when a current of, for instance, .01 ampere runs through the coil, 9.99 amperes will run through the shunt of the instrument. This relation is further explained in the illustration below in which, Fig. 27c represents the circuit diagram of an ammeter.

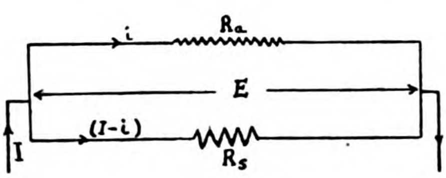


FIG. 27c. CIRCUIT DIAGRAM OF AN AMMETER.

When a current of I amperes runs through the circuit in which the ammeter is connected, an assuming that a current i runs

through the resistance R_a, the current through the shunt R_s will be $I - i$. Since the potential drop E in each resistance is same, we have

$$E = iR_a = R_s(I - i) \tag{26}$$
$$iR_a = IR_s - iR_s$$
$$iR_a + iR_s = IR_s$$
$$i(R_a + R_s) = IR_s$$

$$i = \frac{IR_s}{(R_a + R_s)} \tag{27}$$

and,

$$R_s = \frac{R_a}{n - 1} \tag{28}$$

in which, n stands for numerical quantity to which the current through the instrument is to be multiplied.

When in use, an ammeter is always connected in series with the circuit, thus carrying all the current that is running through the circuit in which it is connected. For measuring relatively smaller currents, a milliammeter, whose scale is graduated to read milliamperes, or one-thousandth of an ampere, is generally used.

(*c*) *The Voltmeter*:—To measure the difference of potential between two points of a circuit, a device known as a voltmeter is used. The voltmeter measures the voltage directly. As in an ammeter, a voltmeter has a moving coil with a high resistance in series. Due to this high resistance a voltmeter receives comparatively small current from the circuit, and hence it may be connected, without being damaged, directly across the source of the current, provided the voltage range of the meter is not exceeded. Fig. 28, below, illustrates the circuit diagram of a voltmeter.

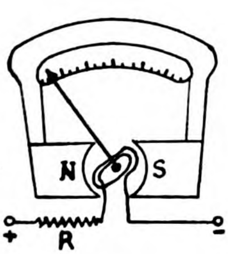


FIG. 28A. THE SCHEMATIC DIAGRAM OF THE VOLTMETER.

FIG. 28B. A COMMERCIAL FORM OF THE VOLTMETER.

The deflection of the moving coil of a voltmeter is proportional to the current passing through it, and hence, when the instrument is properly calibrated it reads the potential in volts, as, according to Ohm's law,

the potential indicated by the instrument is equal to the product of its resistance and the current through it.

At present, there are quite many different types of voltmeters used for a variety of voltage measuring purposes. Among them, the moving coil voltmeter is used for ordinary voltage ranges; the vacuum tube voltmeter is used for detecting and amplifying extremely small current impulses; and, the electrostatic voltmeter, and the sphere-gap voltmeter are generally used in measuring the voltage of high tension circuits.

(d) *The Wattmeter*:—The wattmeter is an instrument that indicates the amount of power consumed in watts. It consists of a combination of both voltmeter and ammeter circuits connected in series-parallel. The wattmeter is always connected between the mains and the load to be measured. A modification of a wattmeter is the watt-hour meter, which registers directly the electrical work expended in watt-hours, or kilowatt-hours.

A wattmeter is seldom employed for general use, as it is more convenient to use a voltmeter and an ammeter together so that the exact voltage and the amperage of the circuit are accurately determined.

2. Measurement of Resistances Connected In Series.—The total resistance of a number of conductors connected in series is equal to the arithmetical sum of the individual resistances of the conductors. In Fig. 29, let R be the total resistance of the conductors r_1, r_2, and r_3. If a current I is flowing in the circuit, then, according to Ohm's law, the fall of potential through the resistance r_1 is Ir_1, through r_2 is Ir_2, and the potential drop at r_3 is Ir_3. The sum of all these individual potential drops is E. Hence the total potential fall is

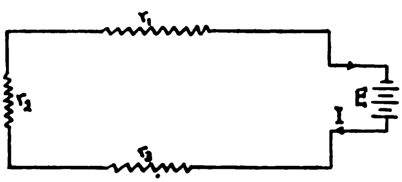


FIG. 29. RESISTANCES CONNECTED IN SERIES.

$$E = Ir_1 + Ir_2 + Ir_3 \tag{29}$$

but,

$$E = IR \qquad \text{where,} \quad R = \text{Total Resistance.}$$

Therefore, by substituting IR for E and isolating I from each term on the right hand side of equation (29), we have

$$IR = I(r_1 + r_2 + r_3)$$

and, dividing both sides of the equation by I, we obtain

$$R = r_1 + r_2 + r_3 \tag{30}$$

Example:—In Fig. 30, three resistances, 20 ohms, 10 ohms, and 15 ohms are connected in series. If the current through them is 2 amperes, (1) What will be the potential drop of the individual resistances? (2) What will be the total resistance of the circuit?

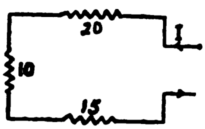


FIG. 30.

Given:

$$r_1 = 20 \text{ ohms.}$$
$$r_2 = 10 \text{ ohms.}$$
$$r_3 = 15 \text{ ohms.}$$
$$I = 2 \text{ amperes.}$$

Assuming that

E_1 = potential drop through r_1
E_2 = potential drop through r_2
E_3 = potential drop through r_3

we obtain,

$$E_1 = Ir_1 = 2 \times 20 = 40 \text{ volts.} \quad \textit{Ans.}$$
$$E_2 = Ir_2 = 2 \times 10 = 20 \text{ volts.} \quad \textit{Ans.}$$
$$E_3 = Ir_3 = 2 \times 15 = 30 \text{ volts.} \quad \textit{Ans.}$$

By equation (30), the total resistance of the circuit will be

$$\begin{aligned} R &= r_1 + r_2 + r_3 \\ &= 20 + 10 + 15 \\ &= 45 \text{ ohms.} \quad \textit{Ans.} \end{aligned}$$

3. The Voltmeter Method of Resistance Measurement.—A quite accurate measurement may be made of the resistance of an unknown conductor by connecting it in series with another conductor whose resistance is known, and then measuring their potentials individually by a voltmeter. The procedure is illustrated diagrammatically in Fig. 31, in which R_s and R_x are respectively the known and unknown resistances of the two conductors connected in series. E is the source of electromotive force, such as from a storage battery, or from a generator.

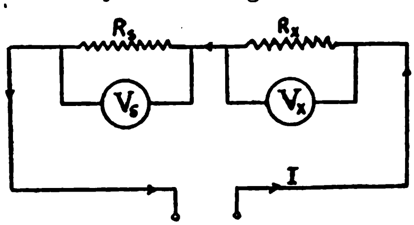


FIG. 31. MEASURING RESISTANCE BY VOLTMETER.

When a current I flows through the circuit constituted by R and R_x, the voltmeter connected across R_s will indicate the potential drop in that portion of the circuit, according to Ohm's law of fall of potential. Hence, the potential drop in R_s will be

$$V_s = IR_s \qquad \text{where, } R_s = \text{Known resistance.}$$

and, similarly, the potential drop in section included by R_x as indicated by the voltmeter will be

$$V_x = IR_x \qquad \text{where, } R_x = \text{Unknown resistance.}$$

Now, by dividing the first equation by the second, we obtain a propor-

tionality of the two circuits as follows:

$$\frac{V_s}{V_x} = \frac{IR_s}{IR_x} = \frac{R_s}{R_x} \tag{31}$$

from which relation we can equate the voltages with the resistances, and formulate for R_s, as shown below:

$$\frac{V_s}{V_x} = \frac{R_s}{R_x}$$

and hence,

$$R_x = \frac{R_s V_x}{V_s} \tag{32}$$

It is obvious from equation (32) that in order to find the unknown resistance of a conductor, the latter is connected with a known resistance of a standard, and the voltage drop across each resistance is measured. The procedure is thus a very simple one, and the result so obtained is quite accurate.

Example:—A standard resistance having 30 ohms is connected in series with a tungsten wire of unknown resistance, as shown in Fig. 32. If the voltage across the standard resistance is 45 volts, and that across the unknown resistance is 30 volts, what is the resistance of the tungsten wire?

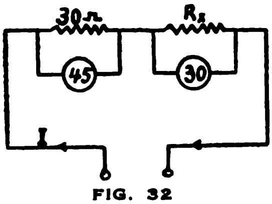


FIG. 32

Given:

$R_s = 30$ ohms.

$V_s = 45$ volts.

$V_x = 30$ volts.

$R_x = ?$

By using equation (32), we have

$$R_x = \frac{R_s V_x}{V_s}$$

$$R_x = \frac{30 \times 30}{45} = \frac{900}{45} = 20 \text{ Ohms.} \qquad \textit{Ans.}$$

4. Measurement of Resistances Connected In Parallel.—When two or more conductors having resistances r_1, r_2, and r_3 are connected to two

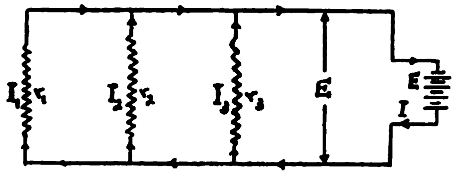


FIG. 33. RESISTANCES IN PARALLEL.

current leads, L and L′, as shown in Fig. 33, the resistances are said to be in parallel with each other. The potential differences across r_1, r_2, and r_3 are equal, but the currents through them are of different magnitudes. By Ohm's law, the current through the resistance r_1 is

$$I_1=\frac{E}{r_1}$$

Similarly, the current through r_2 is

$$I_2=\frac{E}{r_2}$$

and through r_3 is

$$I_3=\frac{E}{r_3}$$

The total current I through all of the resistances is the sum of those through individual branches. Hence, we have

$$I=I_1+I_2+I_3 \tag{33}$$

Substituting the individual currents in equation (33), we obtain

$$I=\frac{E}{r_1}+\frac{E}{r_2}+\frac{E}{r_3} \tag{34}$$

but the total current I is equal to E/R, where R is the total resistance of the parallel circuits. Hence, we may equate

$$\frac{E}{R}=E(\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3})$$

Cancelling E from each side of the equation, we get

$$\frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3} \tag{35}$$

Therefore, the reciprocal of the total resistance of a number of conductors connected in parallel is equal to the sum of the reciprocals of the individual resistances. It will be noticed that the total resistance is less than any one of the resistances alone.

***Example*:—Three incandescent lamps respectively having resistances of 40, 60, and 240 ohms are connected in parallel as shown in Fig. 34. (1) Find the total resistance of the system. (2) If the potential of the circuit is 120 volts, what will be the current through each branch?**

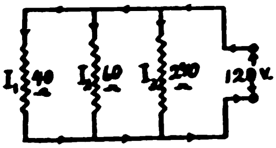


FIG. 34

(1) From equation (35), the total resistance of the system is

$$\frac{1}{R}=\frac{1}{40}+\frac{1}{60}+\frac{1}{240}$$

$$\frac{1}{R}=\frac{6+4+1}{240}=\frac{11}{240}$$

$$R=\frac{240}{11}=21.81 \text{ Ohms.} \qquad \textit{Ans.}$$

(2) The current in each branch will be

$$I_1=\frac{E}{r_1}=\frac{120}{40}=3 \text{ amperes.} \qquad \textit{Ans.}$$

$$I_2=\frac{E}{r_2}=\frac{120}{60}=2 \text{ amperes.} \qquad \textit{Ans.}$$

$$I_3=\frac{E}{r_3}=\frac{120}{240}=.5 \text{ ampere.} \qquad \textit{Ans.}$$

5. Measurement of Resistances Connected In Series-Parallel.—Occasionally, it may happen that in a circuit a number of electric appliances are connected in series, while others in parallel. In such a case, the total resistance of the system may be determined by the arithmetical sum of the

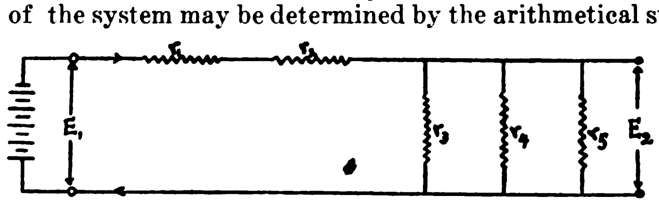


FIG. 35. RESISTANCES IN SERIES-PARALLEL.

series resistances, and the sum of the resistances in parallel. The relation will be clearer when we consider the circuit shown in Fig. 35. The total

resistance in the series portion of the circuit is $r_1 + r_2$, and in the parallel section of the circuit will be

$$\frac{1}{R}=\frac{1}{r_3}+\frac{1}{r_4}+\frac{1}{r_5}$$

from which the numerical value of R is found. Then, the circuit of the system is treated as if consisting of only three resistances connected in series. Hence, we obtain

$$\text{Total Resistance} = R + r_1 + r_2$$

It will be further noticed that the impressed (input) voltage E_1 to the system is greater than the potential E_2 across the parallel circuit. This is due to the fall of potential in the series branch, which potential when deducted from the input potential, the potential across the parallel circuits is obtained. If it is desired to find the currents in the individual parallel circuits, the voltage E_2 should first be determined in the manner stated above.

6. The Wheatstone-Bridge.—Four resistances, one unknown and three adjustable, represented respectively by R_x, and R_1, R_2, and R_3 are connected to a galvanometer G and dry cells C, as shown in Fig. 36.

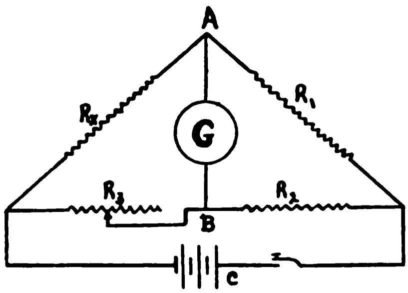


FIG. 36. DIAGRAM OF WHEATSTONE-BRIDGE.

When the resistances are so adjusted that no current flows through the galvanometer, the potentials at points marked by A and B are equal, and the bridge is said to be balanced.

To balance the bridge, the resistances R_1 and R_2 are set to some convenient value, and the resistance R_3 is varied until no current passes through the galvanometer. That is, when a current I_1 flows through R_1 the fall in potential is I_1R_1, and the potential drop when a current I_2 runs through R_2 is I_2R_2. When the bridge is balanced, no current flows through the galvanometer; therefore, the potential drops through resistances R_1 and R_2 are equal, or, the potential at A is equal to that at B. Then we have

$$I_1R_1 = I_2R_2 \tag{36}$$

By similar reasoning, we may conclude that the potential drop through the branch R_x must be equal to that of R_3; hence, the two potentials are

$$I_xR_x = I_3R_3 \tag{37}$$

Since the same current I_1 that passes through R_1 also goes through R_x, the current I_x must be equal to I_1; and, by same reasoning, the currents I_2 and I_3 must be equal.

Substituting the values of the current I_1 and I_2 in the respective terms of the equation (37), we obtain

$$I_1R_x = I_2R_3 \tag{38}$$

which confirms our statement, above, that the potentials across parallel branches are equal.

Dividing equation (38) by equation (36), we have

$$\frac{I_1R_x}{I_1R_1} = \frac{I_2R_3}{I_2R_2}$$

from which equation we obtain

$$\frac{R_x}{R_1} = \frac{R_3}{R_2} \tag{39a}$$

Hence,

$$R_x = \frac{R_1R_3}{R_2} \tag{39b}$$

Since R_1, R_2, and R_3 are always known, the value of R_x can readily be computed by equation (39b).

Although by Wheatstone-bridge method resistance values from 1 to 50,000 ohms can be quite accurately measured, yet below or above this limit, other factors, such as resistance of contact points, heat due to large currents in the circuit, etc., affect considerably the accuracy of measurement. For lower limits of resistance, however, the voltmeter-ammeter method, and for the higher limits a substitution method of measurement is resorted to.

7. The Voltage Divider; The Potentiometer.—Frequently it is desired to obtain a variable voltage from a given source of potential. To accomplish this, a voltage divider consisting of a high resistance rheostat is connected across the potential source, as shown in Fig. 37, in which one end of the rheostat, represented by the resistance R, is connected to the circuit C, or the load. The other lead from the load is slidably connected to some portion of the rheostat, as shown in the figure. When a current I flows through the voltage divider, the potential difference between any two points of the rheostat will be proportional to the distance the two points are separated. For instance, if the distance between the slide S and the binding post P is varied, the potential e to the load C is varied

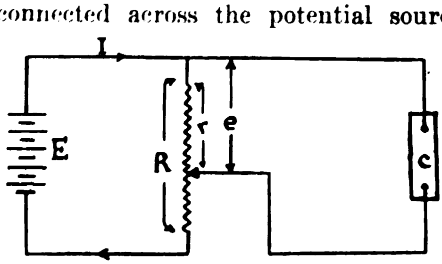


FIG. 37. THE VOLTAGE DIVIDER CIRCUIT.

proportionately. The value of the potential e is determined by equation (16), which gives

$$I=\frac{E}{R}=\frac{e}{r}$$

Hence,

$$\frac{E}{R}=\frac{e}{r} \tag{40}$$

and

$$e=\frac{Er}{R} \tag{41}$$

The equation (41) is generally referred to as the potentiometer formula. A potentiometer is essentially a voltage divider of high precision. It is ordinarily used in measuring the electromotive forces (E.M.F.) of different dry cells by comparison with a Cadmium standard cell, whose electromotive force is 1.083 volts.

8. Specific Resistance.—Already mention has been made in Chapter VI that the resistance is dependent on the length and the diameter of the conductor. The longer the conductor, the higher the resistance; and, the larger the diameter of the conductor the smaller its resistance. Hence, expressing these relations quantitatively, we have

$$R=\frac{\rho L}{A}\text{ ohms per }Cc. \tag{42}$$

where, ρ is the specific resistance, or resistivity, and A is the area of the conductor in sq. cms., and L is its length in centimeters. The resistivity ρ varies with the nature of the conductor and depends on the number of free conduction electrons in the material. The following Table III gives the specific resistance, and the change of resistance per degree centigrade (temperature coefficient) of a few conductors:

Table III, The Specific Resistance and Temperature Coefficient.

Substance	Ohms/Cc at 20°C	a per 1°C change
Silver	1.59×10^{-6}	38×10^{-4}
Copper	1.77×10^{-6}	38×10^{-4}
Aluminum	2.82×10^{-6}	39×10^{-4}
Mercury	95.78×10^{-6}	$8.9\text{x}10^{-4}$
Iron	10.00×10^{-6}	50×10^{-4}

QUESTIONS ON CHAPTER VII

1. (a) Describe, and state how the following are used:—A D'Arsonval galvanometer, ammeter, voltmeter, and wattmeter. Give the circuit diagram of each.
   (b) Derive the formula for the current through the moving coil of an ammeter.
   (c) The moving coil of an ammeter has a resistance of 1000 ohms. If the meter reads 10 amperes on full-scale deflection, what must be the resistance of the shunt so that the instrument can read 50 amperes on full-scale?
2. (a) By what methods can high voltages be measured?
   (b) What magnitude current can be measured by a galvanometer?
   (c) How can you make an ammeter of 10 amperes full-scale rating read 1 ampere on full scale, if the moving-coil has a resistance of 120 ohms?
3. (a) Three electric light bulbs having resistances of 120, 80, and 40 ohms are connected in series. If a potential of 20 volts is impressed across the circuit what will be the current through the bulbs?
   (b) An electric lamp having a resistance of 20 ohms is connected in series with an unknown resistance. If the potential drop across the lamp is 30 volts and across the whole circuit is 75 volts, (1) Find the value of the unknown resistance. (2) What is the current running through the circuit?
4. (a) A potential of 100 volts is impressed across a circuit, in which a heater, having a resistance of 15 ohms, is connected in series with a rheostat. (1) What is the resistance of the rheostat if the potential drop across it is 70 volts? (2) What current is running through the circuit?
   (b) Three resistances, 30 ohms, 40 ohms, and 20 ohms, are connected in parallel in a circuit held at a potential of 120 volts. (1) What is the total resistance of the circuit? (2) What current is running in the system? (3) Find the current in each branch.
5. (a) A Wheatstone-bridge circuit consists of 10 ohms, 40 ohms, 60 ohms, and of a rheostat of unknown resistance. (1) If the rheostat is in series with 60 ohm resistance, find the resistance of the rheostat. (2) If a potential of .4 volt is impressed on the bridge, what will be the current through the branch containing the rheostat?
   (b) A potential of 120 volts is impressed on a voltage divider. If the current through the system is .8 ampere, what must be the resistance of the branch circuit having a potential drop of 40 volts?

CHAPTER VIII

ALTERNATING CURRENTS

1. A General Consideration of Alternating Currents.—We have already seen that a direct current is one in which electrons all flow in one direcion—from the negative pole to the positive pole of the circuit. In the case of an alternating current, the free electrons are displaced periodically back and forth. That is, there is a reversal of direction in the displacement of the electrons as a group during a definite interval of time. Hence, an alternating current is constituted by the systematic vibrations of electrons axially along the conductor without a continuous electron flow. Usually, these periodic changes take place 50 times, 100 times, and 120 times per second in an ordinary lighting circuit.

As an analogy of electron tremor, suppose a cylinder C, shown in Fig. 38, is closed at one end with an elastic membrane M; and, after

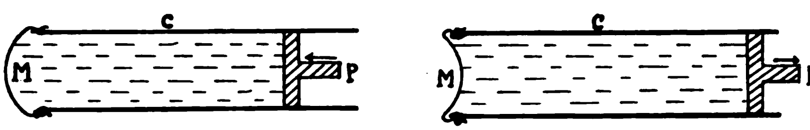


FIG. 38. AN ANALOGY OF ELECTRON CURRENT IN AN ALTERNATING CURRENT CIRCUIT.

the cylinder is filled with a liquid its other end is fitted movably with a plunger P. If the plunger is given a vibratory motion by moving it in and out rapidly, the liquid within the cylinder chamber will move in unison with the motion of the plunger, as noted by the positions of the membrane M, in (a) and (b) in Fig. 38. In an alternating current circuit the motion of the electrons in the conductor will consist of the back and forth movement as of the liquid molecules shown in Fig. 38, except that the motion of the electrons will be much faster.

Alternating currents can be generated at high voltages by the use of step-up transformers. Hence, the transmission efficiencies of such A.C. voltages afford the production of electrical energy in large quantities in a single station, and its distribution over a large territory.

At present, alternating currents are generated at voltages as high as 85,000 volts, and in some locations, at 250,000 volts. At the latter voltage the power can be distributed within a radius of hundreds of miles. This voltage, however, is reduced to 125 or 250 volts before houses or buildings are supplied. Because the alternating currents can be converted easily and at a high efficiency from a current of one available voltage into any other required voltage, they are now in universal use.

Alternating current generators are built in larger units, having high speeds, and the power cost per kilowatt-hour is low. Since, the speed of an

A.C. motor is dependent upon the frequency of the current, which frequency is constant for a given circuit, a constant speed work is thus made possible. In a laboratory, or in a factory, where uniform speed is a primary factor, usually induction or synchronous motors, which are more suitable for this type of work, are used.

2. Generation of Alternating Currents.—In Fig. 39, below, is an alternating current generator represented by two magnetic poles N and S, and a coil of wire rotated on its axis X — X′ in the magnetic field of the poles. The terminals of the coil are connected to slip-rings R and R′. As the coil continuously rotates, the current or E.M.F. generated changes its direction twice during each complete rotation of the coil. This reversal of the direction of the current flow is due to the change of the direction of magnetic lines of force cut by the wire conductor. For instance, when the coil side C cuts lines of force in vicinity of the south magnetic pole the induced E.M.F. will have a direction opposite to that when the same portion of the coil cuts lines of force near the north pole. The result of such an induction is the reversal of current in the conductor every time the conductor approaches the same pole. An A.C. generator consists, therefore, of a large number of these conductors rotating in the field of the generator poles.

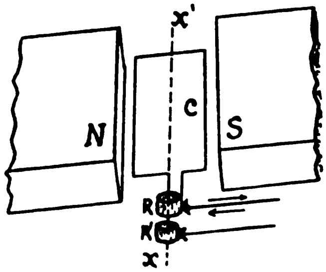


FIG. 39. PRODUCTION OF AN ALTERNATING CURRENT.

3. The Sine-Wave of An Alternating Current.—Suppose we consider an isolated coil from the armature of a motor and placed in the magnetic field of the poles marked by N and S, in Fig. 40. The coil side R at position marked by A is cutting comparatively few lines of force, or none at all. But, as it moves towards the north pole of the field magnet, the lines of force threading the coil increase in number, and when the coil reaches the position B, the magnetic lines through it become maximum. The coil at this position is said to have rotated 90 electrical-time degrees. As the coil continues to move towards C, the magnetic lines of force cut by it will decrease in number, and the coil will have travelled 180 electrical-time degrees. Hence, the induced E.M.F. in the coil will be a maximum at B, and minimum at C, as in A.

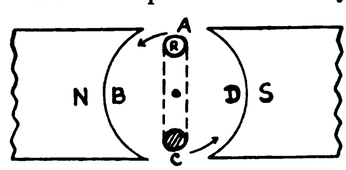


FIG. 40. ALTERNATING E.M.F. PRODUCED IN A COIL OF WIRE.

Similarly, when the coil reaches the position marked by D, a rotation of 270 electrical-time degrees, the induced E.M.F. will again rise to a maximum but its direction will be reversed, since the coil is cutting lines of force near the opposite pole. Finally, as the coil moves on to its original position as at A, the magnetic lines threading through it will diminish to a minimum, and hence the E.M.F., or the current flowing through it. The coil now has made a complete rotation, or 360 electrical-time degrees, during which period the induced E.M.F. has reached twice

each of a maximum value and a minimum value, and its direction is reversed only once. The current thus has made a complete cycle.

During the rotation of the coil, each time the current value reaches a maximum and back to a minimium, or to zero, the current is said to have made one alternation. Therefore, when the armature coil has moved through 180 electrical-time degrees, the current has made one alternation or one-half cycle. When the coil has moved 360 electrical-time degrees, the current has made a complete cycle. A 50-cycle current alternates 100 times, and a 60-cycle current alternates 120 times per second. The ordinary alternating currents are transmitted at 25, 50, and 60 cycles.

Fig. 41 represents the graphical form of a complete cycle, and is called the sine-wave of the current. The sine-wave of an alternating current indicates the instantaneous values of the current intensity, or the voltage, through the generator armature coil at any elecrical-time degree of its rotation. Since the wave curve of a current is plotted by the sine of the successive electrical-time angles made by the coil in respect with two successive unlike poles in the generator, and hence the corresponding change in the magnitude of the induced E.M.F., the curve is generally known as the "sine-wave" of the current.

Supposing a single coil in a generator started at 0, as in Fig. 41, and travelled 90 electrical-time degrees, during which time the induced

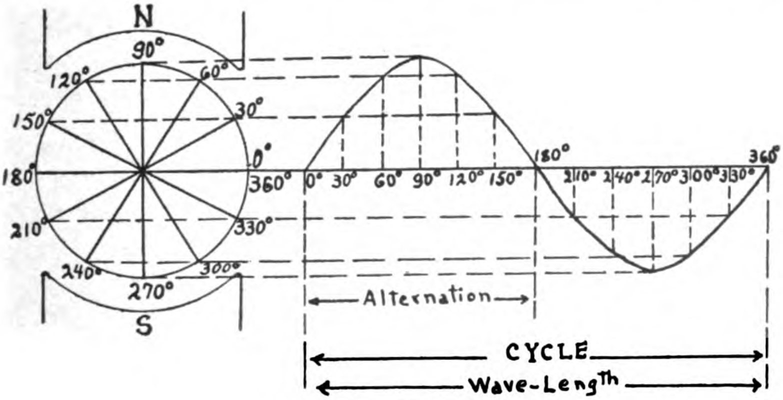


FIG. 41. THE SINE-WAVE.

current increases from zero to a maximum under the north magnetic pole. As the coil travels another 90 electrical-time degrees, the magnitude of the current falls to a minimum, or zero, and the coil has reached 180 electrical-time degree position. The current now is said to have travelled one-half of its wave-length and made an alternation. When the coil advances 90 more electrical-time degrees, it comes under an opposite magnetic pole; and, therefore, the current again rises to a maximum but its direction is reversed. The current finally falls to zero value as the coil, rotating 90 electrical-time degrees further, reaches its starting point. Now, the current has made a complete cycle, or two alternations, in travelling a distance equivalent to its whole wave-length, or 360 electrical-time degrees.

The student should have a thorough understanding of the significance of the sine-wave of an alternating current, since almost all circuits consisting of electromagnetic waves are classified in accordance with their wave-lengths and frequencies.

4. The Wave-Length and The Frequency of An Alternating Current.—As mentioned above, an alternating current moves along a conductor in a wave motion, each wave occurring in a definite interval of time and having uniformly the same length as the one preceding, or following it. Supposing in Fig. 42, below, a current flowing in a conductor reaches from A to C in one second, and makes two alternations. The curve ANBRC represents one cycle, or one frequency, of the current, and its wave-length is determined by the horizontal distance between A and C. Since an electric current travels with the speed of light, 3×10^{10} cms. per second, then the distance between A and C must be 3×10^{10} cms. But, this is the distance covered by the current in question in one second. Therefore, the wave-length of the current is 3×10^{10} cms., and its frequency is one cycle per second. If this current makes 4 cycles per second, then its wave-length will decrease to 1/4th, indicated by AD, in Fig. 42. Hence, we can formulate an equation to designate the relation between the wave-length and the frequency of a current as follows:

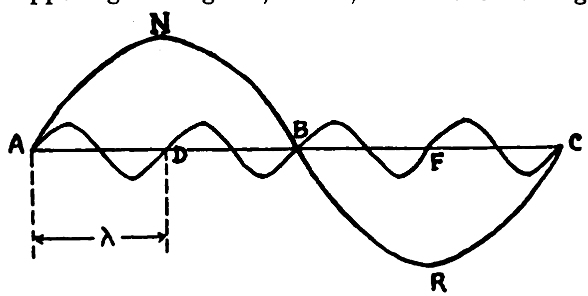


FIG. 42. AN A.C. WAVE CURVE.

$$\lambda = \frac{C}{f} \qquad \text{where,} \quad \begin{aligned} C &= \text{Speed of Light, } 3 \times 10^{10} \text{ cms./sec.} \\ f &= \text{Frequency of Current in cycles.} \end{aligned} \qquad (43)$$

and,

$$f = \frac{C}{\lambda} \qquad \lambda = \text{Wave-length of current in cms.} \qquad (44)$$

It should be noted that the equation (43) or (44) may apply to any radiation of electromagnetic nature. This includes X-rays, visible rays, infra-red rays (heat waves), radio waves, and electric waves.

Examples:—

(1) If a certain electromagnetic wave has a frequency of 600,000 cycles per second, what is the wave-length of the current?

By equation (43), we have

$$\lambda=\frac{C}{f} \qquad \text{where,} \quad \begin{array}{l} C=3\times10^{10}\text{ cms.} \\ f=600{,}000\text{ cycles.}\end{array}$$

$$\lambda=\frac{3\times10^{10}}{600{,}000}=50{,}000\text{ cms., or, } 500\text{ meters.} \qquad \textit{Ans.}$$

(2) What must be the frequency in kilocycles of a radio wave which has a wave-length of 300 meters? (Note:—1 kilocycle is same as 1000 cycles.)

According to equation (44), the frequency is given as

$$f=\frac{C}{\lambda} \qquad \text{where,} \quad \begin{array}{l} C=3\times10^{10}\text{ cms.} \\ \lambda=300\text{ meters, or} \\ \quad 30{,}000\text{ cms.}\end{array}$$

$$f=\frac{3\times10^{10}}{3\times10^{4}}=10^{6}\text{ cycles per sec.}$$

or,

$$f=\frac{1{,}000{,}000}{1000}=1000\text{ kilocycles.} \qquad \textit{Ans.}$$

5. The Effective E.M.F., Current, and Power.—The instantaneous magnitude of the E.M.F. represented by the amplitude of the wave-curve, shown in Fig. 41, is only the peak value of the E.M.F., and not the true or effective value. The pointer of a voltmeter connected across a circuit of this type of current will not follow the true outline of the voltage wave, but it is so designed as to indicate the effective magnitude of the voltage. The effective value, or, the root-mean-square value, of an alternating E.M.F. is then that value which when expended will force an electron flow through a given circuit containing only non-reactive resistance with the same power as a direct-current E.M.F.

The magnitude of the effective E.M.F. may be represented in an equation form as

$$E=\frac{E_m}{\sqrt{2}}=0.707\ E_m \tag{45}$$

in which E_m is the instantaneous maximum potential, or E.M.F., and $\sqrt{2}$ is the ratio between the maximum and the effective values.

Similarly, the effective value of a given current of an alternating circuit is one that will develop the same amount of heat in a non-reactive resistance as a direct-current of same magnitude. For instance, 1 ampere of effective alternating current will produce the same number of calories,

when expended in a resistance, in a given time, as will be produced by a direct-current of 1 ampere under identical conditions. The effective value of an alternating current may be expressd as

$$I=\frac{I_m}{\sqrt{2}}=0.707\ I_m \tag{46}$$

where, I_m is the maximum or peak value of the alternating current.

It is of importance in giving the value of an alternating voltage or current that implication be made as to whether the values are effective or peak. This indication becomes particularly important when considering work done in radiography, since older technics called for the effective values of the voltage, whereas the recent technics are given in crest or peak kilovoltages.

The meters employed in measuring alternating currents or voltages always indicate the effective values. Therefore, when using an A.C. meter, it should be kept in mind that it is the effective and not the crest value of the current, or potential, that is being measured. However, when it is required to change an effective value of either a voltage, or current, to a crest or peak value the effective value should be multiplied by 1.41.

The power expended in an alternating circuit is the product of the maximum value of the current and E.M.F. The effective power of the circuit being given by

$$P=\frac{I_m}{\sqrt{2}}\times\frac{E_m}{\sqrt{2}}=\frac{I_mE_m}{2} \tag{47}$$

where I_m and E_m are respectively the maximum values of the current and voltage.

In terms of the effective values of the current and the voltage, the effective power may be written as

$$P=IE\cos\theta \tag{48}$$

in which, $\cos\theta$ is called the *power factor* and is equivalent to the angular difference in electrical-time degrees between the voltage and the current. This difference, however, amounts almost to zero in ordinary power transmission, or when power is expended in a circuit containing only resistance. Hence, we have the relation

$$P=IE\cos\theta=I^2R \tag{49}$$

where, the two quantities, the current and the potential, are taken as effective.

6. Phase Angle Relations.—(a) *Cicuits Having Ohmic Resistance.*—In an alternating current circuit containing ohmic resistance only, the instantaneous magnitude of the current is equal to the voltage at that instant divided by the resistance of the circuit, since under these conditions the variations in current magnitude keep exact step with the acceleration of

electron flow due to the voltage. Therefore, we say that the current and the voltage rise and fall simultaneously. This relation is further observed in Fig. 43, below, in which E is the effective voltage driving an effective current I through the circuit containing ohmic resistance. Since, in a circuit the resistance R is constant, the potential difference IR (or E) varies as the current and is always in phase with it. The power expended in such a circuit is equal to the product of the effective voltage and the current, or, to I^2R, as in a direct-current circuit. The power factor is then unity.

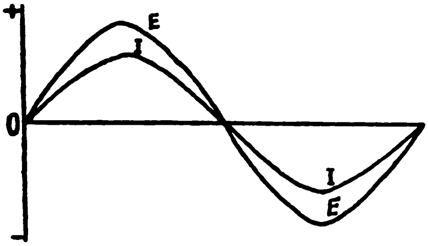


FIG. 43. VOLTAGE AND CURRENT IN PHASE IN A RESISTIVE CIRCUIT.

(*b*) *Circuits Having Inductive Resistance.*—In a circuit having an inductive resistance but no ohmic resistance, the current wave lags 90 degrees behind the voltage wave which prorduces it. This is shown in Fig. 44, in which the voltage is 90 degrees ahead of the current. That is, when the voltage is at its maximum, the current has a zero magnitude, and vice versa. In a circuit such as this, it is said that the *phase angle* between the current and the voltage is 90 degrees, the voltage leading the current.

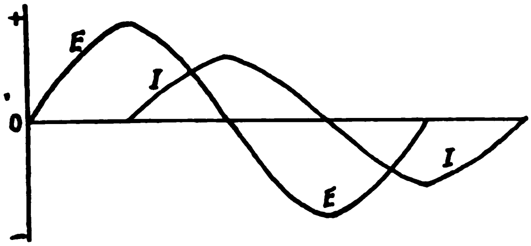


FIG. 44. THE VOLTAGE LEADING THE CURRENT BY 90 DEGREES IN AN INDUCTIVE CIRCUIT.

An inductive circuit may be explained as one having a resistance due to an induced counter-electromotive force in the circuit. Such a counter-electromotive force is prevalent in a conductor shaped into a coil consisting of relatively a large number of turns but not necessarily having any amount of ohmic resistance were this coil a straight wire. As was shown in a previous chapter, when a current flows in a coil, magnetic lines of force are set up around the coil, and a counter-electromotive force (opposing E.M.F.) is produced which offers a resistance to the flow of current through the conductor. This apparent resistance due to the induced E.M.F. is called an *inductive resistance,* and the circuit is known as having an inductance.

The effective voltage in an inductive circuit, when ohmic resistance is entirely neglected, is equal to $2\pi fLI$, where f is the frequency of the effective current I, and L is the inductance of the circuit. Hence, the division of voltage by the current gives a quantity $2\pi fL$, which is known as the inductive resistance and is designated by X_L. Thus, for a purely inductive circuit

$$E = 2\pi fLI = IX_L \text{ volts.} \tag{50}$$

and,

$$I = \frac{E}{2\pi fL} = \frac{E}{X_L} \text{ amperes.} \tag{51}$$

hence,

$$X_L = \frac{2\pi fLI}{I} = 2\pi fL \text{ ohms.} \tag{52}$$

where, if the frequency f is zero, the X_L becomes zero.

In a circuit having pure inductance, no power is expended in maintaining an alternating current. This fact will be further evident when we consider a circuit, Fig. 45a, consisting of a coil of wire carrying a current I impressed with a potential E. The power expended, according to equation (48), will be given as

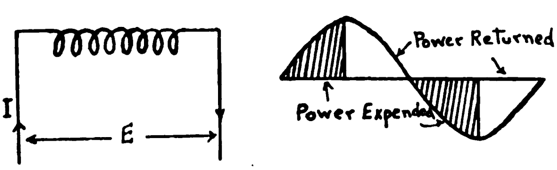
$$P = EI \cos\theta$$

Since, in pure inductance, the current is 90 degrees out of phase with respect to the voltage, the latter leading, then the angle θ is equal to 90 degrees.

But, $\cos 90° = 0$

and hence, $P = EI \times 0$

where, the power expended is shown to be equal to zero.



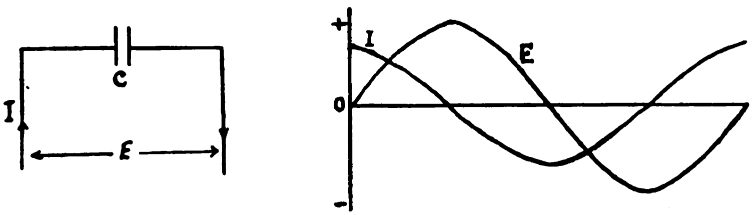
(A) (B)

FIG. 45. POWER EXPENDED IN AN INDUCTIVE CIRCUIT.

As shown in Fig. 45b, the power in the first half alternation is expended to build a magnetic field around the coil when the current is increasing, and during the decrease of current the energy of the magnetic field is drawn from space back to the coil with the result that no expenditure of power is effected.

(c) *Circuits Having Capacitive Resistance.*—The quantity of electricity stored in a condenser connected in a circuit, such as shown in Fig.

46a, is proportional to the capacity (capacitance) of the condenser to hold charges and to the difference of potential existing between the ter-



(A) (B)

FIG. 46. THE CURRENT AND VOLTAGE IN A CAPACITIVE CIRCUIT.

minals of the condenser. That is, the equation for the quantity of charge Q on a condenser of capacity C impressed with a voltage E is given as

$$Q = CE \tag{53}$$

where, the charge Q is given in coulombs, the capacitance C in farads, and E in volts.

Since the extent of the strain upon the dielectric of a condenser is dependent upon the applied voltage, the charging current will continue to flow as long as the voltage is rising and falling but will become zero as soon as the voltage ceases to change in value.

The condenser is charged and discharged twice every complete cycle, and hence, the electric charge is transferred through the circuit twice in one direction and twice in the other. It is obvious, therefore, that a direct-current can not be sent through a capacitive circuit, since there are no fluctuations in the magnitude of the voltage charging the condenser.

The current in a capacitance circuit leads the impressed voltage by 90 degrees, as shown in Fig. 46b. Accordingly, the phase difference between these two quantities is 90 degrees.

The magnitude of the current through a condenser is given as

$$I = 2\pi fCE = EX_C \text{ amperes.} \tag{54}$$

and,

$$E = \frac{I}{2\pi fC} = \frac{I}{X_C} \text{ volts.} \tag{55}$$

Hence, the capacitive reactance X_c of the circuit will be

$$X_C = \frac{I}{2\pi fCI} = \frac{1}{2\pi fC} \text{ ohms.} \tag{56}$$

where, C is the capacitance in farads, and the values of E and I are effective.

From the foregoing discussions, it will be evident that an increase in capacitance and in frequency will increase the current through the circuit, while in an inductance circuit the current decreases with increase

in inductance and frequency. These relations may become clearer by having a glance at the equations (51), and (54).

7. Circuits Having Resistance, Inductance, and Capacitance.—We have already seen that Ohm's law strictly holds for the determination of the potential difference between any two points in a circuit containing resistance only, and the fall in potential is given as the product of the resistance and the current flowing through it. Thus, we have the relation, as given in equation (17)

$$V=IR$$

where, the values V and I are effective.

But, for a circuit containing both resistance and inductance in series, this relation is somewhat modified. The apparent resistance of the circuit is found by the square root of the sum of the squares of the individual resistances in each branch, since the potential drop in the inductive circuit is leading that of the circuit containing resistance by 90 degrees. The total resistance, or, the impedance, represented by Z, of the circuit will then be expressed as

$$Z=\sqrt{R^2+X_L^2} \quad \text{ohms.} \tag{57}$$

or,

$$Z=\sqrt{R^2+(2\pi fL)^2} \quad \text{ohms.} \tag{58}$$

where, the inductance is given in henrys, and f in cycles per second.

The potential drop across the circuit is

$$IZ=I\sqrt{R^2+(2\pi fL)^2} \quad \text{volts.} \tag{59}$$

or

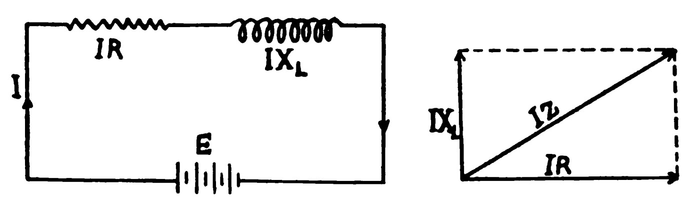
$$E=IZ \text{ volts.} \tag{60}$$

and,

$$I=\frac{E}{Z} \text{ amperes} \tag{61}$$

in which, E and I are taken as effective.

Since, in alternating currents like electrical quantities are added vec-



(A) (B)

FIG. 47. CIRCUIT CONTAINING RESISTANCE AND INDUCTANCE IN SERIES.

torially, the potential drop across a circuit containing both resistance and inductance, as shown in Fig. 47, is represented by the magnitude of the hypothenus of a parallelogram whose sides are constituted by the vector magnitudes of the potential drop IX_L in the inductive branch and the potential drop IR in the resistive portion of the circuit. The potential in the inductive circuit is leading that of the resistive branch by 90 degrees. Fig. 47b gives the graphical representation of the two vector quantities in the form of a parallelogram, whose sides and the hypothenus denoting the corresponding potential values.

***Example*:—A circuit having a resistance of 20 ohms and an inductance of .5 henry is impressed with an effective potential of 110 volts at 60 cycles.**

(1) What will be the inductive reactance? (2) What will be the impedance of the circuit? (3) Find the current through the circuit.

(1) By equation (52), the inductive reactance of the circuit is

$$X_L = 2\pi f L \qquad \text{where, } f = 60 \text{ cycles.} \quad L = .5 \text{ henry.}$$

and,

$$X_L = 2 \times 3.1416 \times 60 \times .5$$
$$= 188.5 \text{ ohms.} \qquad \textit{Ans.}$$

(2) The impedance will be

$$Z = \sqrt{R^2 + (2\pi f L)^2} \qquad \text{where, R} = 20 \text{ ohms.}$$

$$= \sqrt{(20)^2 + (188.5)^2}$$

$$= \sqrt{400 + 35{,}532}$$

$$= \sqrt{35{,}932} = 189.6 \text{ ohms.} \qquad \textit{Ans.}$$

(3) According to equation (61), the current will be

$$I = \frac{E}{Z} \qquad \text{where, } E = 110 \text{ volts.} \quad Z = 189.6 \text{ ohms.}$$

$$I = \frac{110}{189.6} = .58 \text{ ampere.} \qquad \textit{Ans.}$$

In the case of a circuit containing both resistance and capacitance connected in series, as shown in Fig. 48a, where, the potential in the resistive branch is leading the potential in the capacitive branch by 90 degrees, the vector sum IZ of the two potential drops is determined by the same method as in an inductive impedance circuit, except that the vector IX_c is indicated in a negative direction. Therefore, the parallelogram formed by the potential vectors will have its hypothenus represent-

ing the total potential drop in the circuit and directed downwards, as shown in (b).

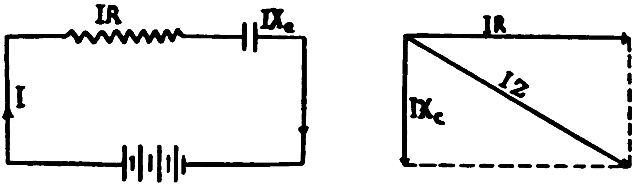


FIG. 48. CIRCUIT CONTAINING RESISTANCE AND CAPACITANCE IN SERIES.

The total potential drop IZ across the circuit may be expressed by

$$IZ = I\sqrt{R^2 + X_c^2} \text{ volts} \tag{62}$$

where, X_c is the capacitive reactance of the circuit and is equal to $1/2\pi fC$; and, hence, the equation (62) may be written as

$$IZ = I\sqrt{R^2 + (1/2\pi fC)^2} \text{ volts.} \tag{63}$$

$$Z = \sqrt{R^2 + (1/2\pi fC)^2} \text{ ohms} \tag{64}$$

where, C is given in farads, and f in cycles per second.

Example:—A potential of 110 volts and 60 cycles per second is impressed on a circuit having a resistance of 8 ohms, and a capacitance of 10 microfarads. (1) What is the capacitive reactance of the circuit? (2) What is the impedance of the circuit? (Note:—1 microfarad is equal to 10^{-6} farads.)

(1) The capacitive reactance, according to formula (56) is

$$X_c = \frac{1}{2\pi fC} \qquad \text{where, } \begin{array}{l} f = 60 \text{ cycles.} \\ C = 10 \times 10^{-6} \text{ farads.} \end{array}$$

$$X_c = \frac{1}{2 \times 3.1416 \times 60 \times 10 \times 10^{-6}}$$

$$X_c = \frac{10^5}{377} = 265.25 \text{ ohms.} \quad \textit{Ans.}$$

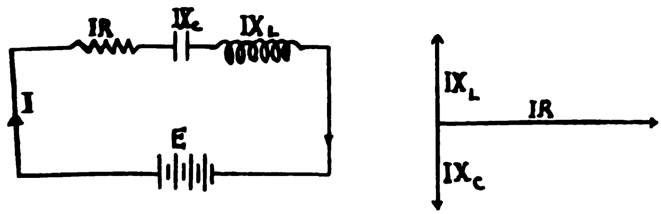
(2) The impedance of the circuit is

$$Z = \sqrt{R^2 + (1/2\pi fC)^2} \qquad \text{where, R} = 8 \text{ ohms.}$$

$$= \sqrt{64+\left(\frac{1}{2\times3.1416\times60\times10\times10^{-6}}\right)^2}$$

$$= \sqrt{70{,}421.5} = 265.37 \text{ ohms. } \textit{Ans.}$$

Assuming that a series circuit consists of a resistance, inductance, and capacitance, as shown in Fig. 49. It will be noted from the vector diagram represented in (b) that the vector direction of IX_c is opposite



(A) (B)
FIG. 49. SERIES CIRCUIT CONTAINING R, L, AND C.

to that of IX_L, and the resultant potential will be equal to the difference of the two potentials, since the latter are opposing each other by having a phase difference of 180°. Hence the equation for the total potential drop across the circuit may be given as

$$IZ = I\sqrt{R^2+(X_L - X_c)^2} \text{ volts.} \tag{65}$$

or,

$$IZ = I\sqrt{R^2+(2\pi fL - 1/2\pi fC)^2} \text{ volts.} \tag{66}$$

$$Z = \sqrt{R^2+(2\pi fL - 1/2\pi fC)^2} \text{ ohms.} \tag{67}$$

Example:—A circuit having a resistance (R) of 10 ohms, an inductance of .2 henry, and a capacitance of 40 microfarads is held at a potential of 110 volts and 60 cycles per second. (1) Find the impedance of the circuit. (2) What will be the current through the circuit?

(1) By equation (67), we have

$$Z = \sqrt{R^2+(2\pi fL - 1/2\pi fC)^2}$$

where,
$R = 10$ ohms.
$L = .2$ henry.
$C = 40 \times 10^{-6}$ farads.
$f = 60$ cycles/sec.

$$Z = \sqrt{(10)^2+(2\times 3.1416\times 60\times .2 - \frac{1}{2\times 3.1416\times 60\times 40\times 10^{-6}})^2}$$

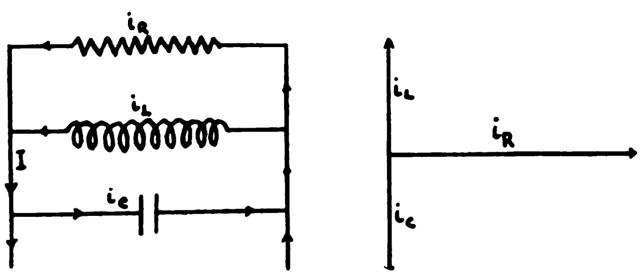
$$= \sqrt{100+(75.4 - \frac{10^6}{1508})^2} = \sqrt{100+(75.4 - 66.3)^2}$$

$$= \sqrt{100+(9.1)^2} = \sqrt{100+82.81}$$

$$= \sqrt{182.81} = 13.5 \text{ ohms.} \quad \textit{Ans.}$$

In dealing with alternating current potentials impressed on divided circuits, the resistance, or, the current, in each branch is calculated as though each branch were a series circuit, as by equation (61). To determine the total current flowing in the system the currents in the individual branches are added vectorially.

In Fig. 50a is shown a circuit containing a resistance, an inductance, and a capacitance. If a current I is running through the system held at a



(A) (B)
FIG. 50, CIRCUIT CONTAINING R, L, AND C CONNECTED TOGETHER IN PARALLEL.

potential E, the current in each branch is found by dividing E by the corresponding resistance. The total current I will then be given by

$$I = \sqrt{i_r^2 + (i_L - i_c)^2} \tag{68}$$

in which, the subscripts designate the branch in which the corresponding current is running.

The vector diagram of the branch currents is given in Fig. 50b, from which it is evident that i_c is lagging i_L by 180°, hence, their direction of flow in the circuit will be opposite, as indicated by arrows in Fig. 50a.

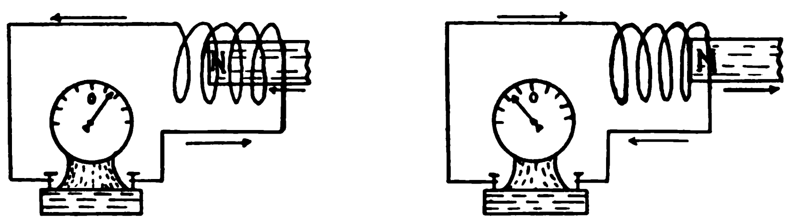
QUESTIONS ON CHAPTER VIII

1. (a) Explain the motional behavior of the electrons in an alternating current circuit.
   (b) If an alternating current is not constituted by a stream of electrons flowing from one end of the conductor to the other, how is the flow of this current realized?
   (c) What are the advantages of generating an electric power as alternating current?
2. (a) Illustrate with a diagram how an alternating current can be generated.
   (b) What is a sine wave? What significance is held by a knowledge of the sine wave of an alternating current?
   (c) What is the frequency of a certain electromagnetic wave having a wave-length of 1.5×10^4 Angstrom units?
3. (a) Explain what is meant by the effective, and peak values of an alternating current.
   (b) Is it the effective or the maximum value of an alternating current that is indicated by an A.C. meter? Explain why.
   (c) What is a power factor? What is the nature of a circuit having a power factor of one?
   (d) In an alternating current circuit, what is meant by phase angle?
4. (a) An alternating current of 3.5 amperes (maximum value) flows through a resistance of 20 ohms. If the angular difference in electrical time degrees between this current and its voltage is zero, (1) What is the value of the peak voltage? (2) How much power is expended in this resistance?
   (b) How can you explain the fact that an alternating current running in a circuit having a pure resistance keeps in phase with the voltage?
   (c) What is meant by an inductive resistance? An impedance?
   (d) Show by an illustration that no power is expended in sustaining an alternating current in a pure inductive circuit.
5. (a) A 60-cycle alternating current circuit consists of three branch circuits connected in parallel, and contains respectively 30 ohms in the resistive circuit, an inductance of 2 henrys in the inductive circuit, and 30 microfarads in the capacitive circuit. If the potential applied on the system is 120 volts, (1) What will be the reactance of the inductive circuit? (2) What will be the reactance of the capacitive circuit? (3) What will be the current through each of the three branches? (4) Find the total current running through the circuit.
   (b) If the three branched circuits in (a) are connected in series, what current will flow through the new circuit?

CHAPTER IX

INDUCTION OF ELECTROMOTIVE FORCES

1. The Induction of E.M.F. by A Magnet. In the early part of the nineteenth century, Faraday discovered that when a magnet is moved in a coil of wire connected to a D'Arsonval galvanometer a momentary deflection of the needle is produced, indicating an induction of a momentary current in the coil. He also observed that inserting the magnet into the coil produced a momentary current in one direction, as in Fig. 51a, and withdrawing it from the coil produced a current in the opposite direction, as in Fig. 51b. The more rapidly the magnet was moved the greater was the magntitude of the induced current, and that the current existed only while the magnet was in motion. The current thus produced is frequently referred to as *Faradic current*.



(a) (b)

FIG. 51. INDUCTION OF E.M.F. BY A MAGNET.

These experiments of Faraday, later improved by Henry, laid the first foundations of the generation of electricity by induction of magnetic fields, from which phenomenon is now grown the huge modern power and light industry. The present power generation, however, depends for its magnetic fields not upon permanent magnets but on electromagnets with very strong magnetic fields. In a generator, the poles produce large magnetic fields, which thread the armature coils inducing a flow of current externally known as the electric power.

The production of a flow of current in the armature of a generator may further be explained by the phenomenon of free electron displacement in the atoms of any conductor when subjected to the influence of a moving magnetic field. This effect may be observed to occur just as effectively as when the conductor is moved in a stationary magnetic field.

Assume a north pole N of a magnet, Fig. 52a, to be moving downward and at right angles to the axis of a stationary conductor B. Each free electron in the conductor will be surrounded by a magnetic field which will strengthen the magnetic field on the left side of the electron. The increase of the magnetic flux at the left of the electron will exert a force on the electron displacing it to the right and at right angles to the

magnetic field. Thus, the migration of the electrons from one end of the conductor to the other will cause the two ends of the conductor to become oppositely charged, establishing an electrostatic field at each end of the conductor, as shown in (b). But as soon as the motion of the mag-

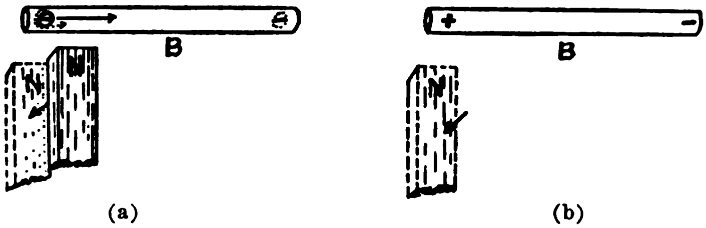


FIG. 52. THE ELECTRON DISPLACEMENT IN A CONDUCTOR BY A MOVING MAGNETIC FIELD.

netic field ceases, the displaced electrons re-assume their original state, thus destroying the electrostatic fields. The forces in the conductor then return to a state of equilibrium. Thus, in the induction of a current in a conductor, the magnetic field should be constantly changing in order to produce a continuous displacement of electrons in the conductor, and hence the flow of current.

In the induction of magnetic forces in a conductor what primarily takes place is the development of an electromotive force, and that the current is a secondary effect. The E.M.F. thus produced drives the electrons through the conductor, producing a flow of current. Therefore, we may conclude that the inducing magnetic field produces a motive force, which accelerates the electrons in the conductor in the direction of the potential gradient.

2. The Induction Of E.M.F. In A Coil Of Wire.—When two independent coils of insulated copper wire are wound around a soft iron core, as in the accompanying Fig. 53, and a current is sent through one of the coils, A, an induced current will be produced in the coil B at the moment the circuit is closed, as evidenced on a galvanometer G connected to the terminals of the coil B. When the current is interrupted in A, there will

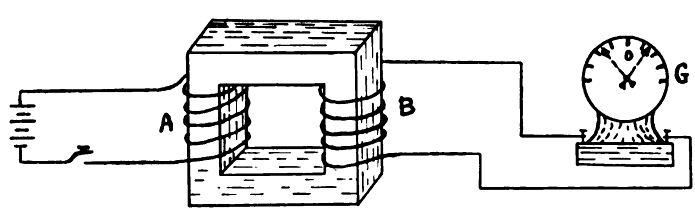


FIG. 53. INDUCED E.M.F. IN A COIL.

be another momentary flow of current in the coil B, but the direction of flow will be opposite to that of the first induction.

In the above experiment, calling the coil A the primary winding, and the coil B, the secondary, increasing the magnetic field in the primary

produced an induced current in the secondary, and decreasing the magnetic field in the primary coil again induced a current in the secondary coil but the direction of the flow was reversed. A system such as this represents the principle of a transformer, which will be found to be of importance in controlling the E.M.F. and the current in circuits to be taken up in later chapters.

3. The Law Of Induced Electromotive Forces.—From the foregoing sections, it becomes apparent that two insulated coils independently wound around an iron core and a current sent through one of the coils, the primary, an electromotive force is induced in the secondary coil. The magnitude of the electromotive force thus produced depends upon the rate of change of current and hence the magnetic field in the primary coil. The more rapidly the magnetic field is changed the greater the induced electromotive force obtained. Therefore, putting these relations in the form of a law: *In a coil of wire of N turns, the induced electromotive force (E.M.F.) is directly proportional to the rate of change of the number of inductance lines (maxwells) threading through the coil and the number of turns of wire in the coil.*

The above law may be written in an equation form as

$$\text{Induced E.M.F.} = N\frac{\phi_1 - \phi_0}{t} \quad \text{electromagnetic units.} \tag{69}$$

where, N stands for the number of turns, ϕ_0 is the lines of force at the start, ϕ_1 the maximum flux, and t is the time of flux change and is given in seconds.

Furthermore, one line of force is equal to one C.G.S. electromagnetic unit, and one-hundred million (10^8) C.G.S.E.M. units make one practical volt. Hence, converting the equation (69) to practical volts, we obtain

$$E = N\frac{\phi_1 - \phi_0}{\mathrm{t} \times 10^8} \quad \text{volts.} \tag{70}$$

in which, E stands for the E.M.F. in volts.

The equation (70) may also be expressed in the following form:

$$E = \frac{N\Delta\phi}{t10^8} = L\frac{I}{t} \tag{71}$$

from which we obtain

$$L = \frac{N\Delta\phi}{10^8 I} \quad \text{henrys.} \tag{72}$$

in which, L is the inductance in henrys, $\triangle\phi$ is the rate of flux change, and I the current in amperes.

The above formulae strictly follow Lenz' Law, which states that *when an electromotive force is induced in a conductor the direction of the electromotive force is such as to produce a current whose magnetic field will*

oppose the change. The E.M.F. thus induced depends upon the inductance L and the change of current per second. The inductance is given in henrys. A *henry* is that inductance which produces an induced electromotive force of 1 volt when the inducing current is changed at the rate of 1 ampere per second.

Example:—If a coil of wire, having 500 turns and an area of 400 sq. cms., is rotated 90 degrees in 1/5th of a second about its axis in a magnetic field having a strength of 5 C.G.S.E.M. units, (1) What will be the total magnetic lines of force threading through the coil? (2) What will be the E.M.F. produced?

(1) Total Flux = Pole Strength x Area (equation 5)

$$\phi = BA = 400 \times 5 = 2000 \text{ maxwells. } \textit{Ans.}$$

(2) The induced E.M.F. is found by equation (70), which gives

$$E = N\frac{\phi_1 - \phi_0}{t \times 10^8} \qquad \text{where,} \quad \begin{aligned} N &= 500 \text{ turns.} \\ \phi_1 &= 2000 \text{ maxwells.} \\ \phi_0 &= 0 \text{ maxwells.} \\ t &= 1/5\text{th second.} \end{aligned}$$

$$E = \frac{500 \times 2000}{(1/5) \times 10^8}$$

$$= \frac{500 \times 2000 \times 5}{100{,}000{,}000}$$

$$= 0.05 \text{ volt.} \quad \textit{Ans.}$$

4. Induced E.M.F. Produced By A Pulsating Direct Current.—It was mentioned previously that in order to produce an induced electromotive force in a conductor, the current in the circuit inducing the electromotive force should fluctuate periodically, or, should be interrupted at definite rapid intervals. That is to say, if the current in the conductor inducing the electromotive force is broken and closed to produce a periodic succession of rise and fall in the current value, there will be a periodic increase and decrease in the number of lines of force induced in the secondary coil. Should it, therefore, happen that the current available is a direct current, then in order to induce an electromotive force a suitable switching mechanism should be provided so as to effect a periodic fluctuation of the inducing current.

Since 100,000,000 lines of force per second produce one practical volt, the magnitude of the induced voltage in the secondary will depend upon the rapidity with which the lines of force will change in the inducing magnetic field.

In Fig. 54, below, a current is sent through the insulated copper wire C and the interrupter A, then into a coil P, the primary coil, and back to the generator G. Another coil of insulated wire S, the secondary, of smaller diameter wire, is wound around the primary and well insulated from it. The number of turns in the secondary winding is relatively

greater than that of the primary coil. The two terminals of the secondary coil are connected to an incandescent lamp in series.

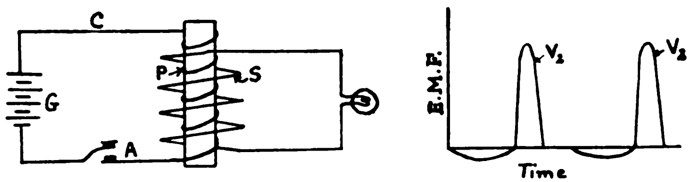


FIG. 54. INDUCTION OF E.M.F. BY A PULSATING D.C.

As the current is interrupted at A, the vibrating switch, there will be a periodic formation of magnetic flux around the primary coil P. This flux, in turn, will thread the secondary coil S, inducing in it an electromotive force, which will light the lamp.

During each closing of the current in the primary, by the interrupter, the induced current impulse in the secondary will ascend to its maximum, but the electromotive force will be relatively small. When the current is broken in the primary, the current in the secondary will start to diminish and will change its direction of flow, but the electromotive force will rapidly rise to its maximum and then will fall back to zero. Hence, the induced current in the secondary will have a high voltage and low amperage at break of the current in the primary, and a high amperage and low voltage at closing of the circuit, as shown graphically in (b). Obviously, then, the current through the secondary is never uniform or direct-current, but it consists of impulses depending on the rate of interruption and the change of current in the primary coil of the transformer.

5. Induced E.M.F. Produced By A.C.—A primary coil carrying an alternating current also will induce an electromotive force in the secondary coil for the same reason as in a pulsating direct-current. In the case of an alternating current, however, the current in both the primary and secondary coils will alternate twice every cycle of the alternating current input, executing more or less a uniform sine-wave motion, as shown in Fig. 55. With a 60-cycle current, the direction of the E.M.F. in both the primary and the secondary coils will change 120 times per second, and 100 times per second for a 50-cycle current. Thus, during induction of electromotive forces, the frequency of the induced current remains same as that of the inducing current.

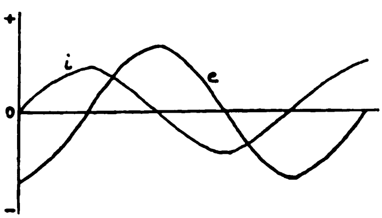


FIG. 55. THE WAVE-CURVE OF A.C. INDUCTION.

6. The Transformer.—The device described above as utilizing the principle of induction in transforming one voltage to another is tech-

nically known as a transformer. A simple transformer essentially consists of a soft iron closed core, or frame, as shown in Fig. 56, and two independent coils of insulated copper wire wound around each of the two opposite sides of the core. One of these coils is called the primary, and the other the secondary coil of the transformer. Depending as to whether the number of turns of wire in the secondary is larger or smaller than that in the primary coil, the device becomes either a step-up or a step-down transformer.

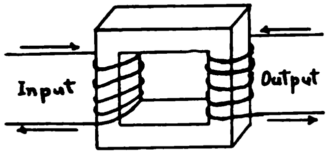


FIG. 56. A CLOSED-CORE TRANSFORMER.

A step-up transforemr consists of relatively more turns of fine wire in its secondary than that in the primary, and thus it produces a higher voltage than the voltage applied. This arrangement is exactly reversed in a step-down transformer, and hence a lower voltage is obtained from it than the voltage applied. A third type, known as the insulating transformer, consists of exactly the same number of turns of wire on either side of the transformer, thus retaining a duplicate voltage in the secondary of that applied on the primary coil.

The core of the transformer is built up of soft sheet iron laminations coated with a film of oxidized material to insulate one layer from the other, thus preventing the flow of eddy current (electric currents set up in the interior of the iron) from one of the laminations to the other. When this coating is neglected, the core will heat up abnormally, causing a proportionate waste of input energy. The core is further insulated from the windings by a tube of fiber, bakelite, or by other insulating materials, depending on the voltage on each set of winding.

When an alternating current is sent through the primary coil of a transformer, the soft iron core becomes magnetized, and the magnetic flux through it will change its course first in one direction, and then to the reverse. Consequently, the magnetic field around the core will change in intensity and direction with each alternatioin of the current through the primary coil, producing in the secondary coil an induced electromotive force of the same frequency as that of the current in the primary coil.

The magnitude of the induced electromotive force will depend upon the frequency of change of the magnetic field and upon the number of turns of the secondary winding. The electromotive force in the secondary will further vary with the ratio of the number of turns in its winding to the number of turns in the primary winding.

Assuming that there are twice as many turns of wire in the secondary as in the primary, the induced E.M.F. through the former will be doubled; if the secondary has half as many turns as in the primary, then the induced E.M.F. in the secondary coil will be half as great as that in the primary winding. The first example illustrates the principle of a step-up transformer, while the second illustrates the principle of a step-down transformer. The power output in the transformer, however, is theoretically equal to the input. Each transformer has a factor called "*the*

transformer constant," which is the ratio of the number of turns in the primary to that of the secondary coil of the transformer. The ratio of the transformer is given as 1:10, 1:20, 1:100, etc.

We have already seen that when a large quantity of power is transmitted at high voltage, the current will be small, and the loss in transmission lines due to I^2R will be small, and when power is transmitted at high amperage and low voltage, there will be a great loss of power in the line due to the production of heat in the transmitting conductor, as by the formula I^2R. Hence, the transformer finds its importance in the stepping-up of the voltage before the power is transmitted to long distances.

Transformers used for high power transmission as well as those used in an X-ray machine are usually immersed in a heavily insulating oil, which prevents the possible spark-over from the high tension side of the transformer to some other point, thus obviating the possible destruction of the transformer, or its parts. The oil also cools the low tension winding that carries a comparatively large current. The oil-immersed transformers used for high tension current transmission are enclosed in iron boxes, and mounted, in turn, on top of the transmission poles in the streets or roads.

The wires from the mains, carrying between 2200 to 22,000 volts, or more, in the vicinity of a city limit, are connected to the primary coils or the high tension side of the transformer. The wires going into houses or buildings are connected to the secondary or low tension side of the transformer, which reduces the voltage to 110 or 220 volts before the power is distributed.

7. The Transformer Formulae.—Mention was made in the foregoing sections that the induced E.M.F. in a coil depends upon the number of turns of wire in that coil. Therefore, in a transformer, the ratio of the voltage to the number of turns in the primary coil is equal to the ratio of the secondary voltage to its number of turns. Putting this in the following rule forms:

(a) The E.M.F. (voltage) induced in a secondary coil of a transformer is directly proportional to the primary voltage and to the number of secondary turns, and inversely proportional to the number of the primary turns.

Thus, we have

$$\frac{V_2}{N_2}=\frac{V_1}{N_1} \tag{73}$$

and,

$$V_2=\frac{N_2\times V_1}{N_1} \tag{74}$$

in which, V_2 is the secondary voltage, V_1 the primary voltage, and N_1 and N_2 are respectively the number of turns in the primary and secondary windings.

Example:—A voltage of 110 volts is impressed on the primary coil of a transformer having 100 turns in its primary and 1000 turns in the secondary windings. (1) What will be the voltage in the secondary? (2) What will be the transformer constant?

(1) By equation (74), we have

$$V_2 = \frac{N_2 \times V_1}{N_1} \qquad \text{where,} \quad \begin{aligned} N_2 &= 1000 \text{ turns.} \\ N_1 &= 100 \text{ turns.} \\ V_1 &= 110 \text{ volts.} \end{aligned}$$

$$V_2 = \frac{1000 \times 110}{100} = 1100 \text{ volts.} \quad \textit{Ans.}$$

(2) The transformer constant will be the ratio of the number of turns between the two windings. Hence we have

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{100}{1000} = \frac{1}{10} \text{ or, } 1 : 10 \qquad \textit{Ans.}$$

(b) Since the induced electromotive force in a coil is inversely proportional to the induced current, it follows that in a transformer the induced E.M.F. in the secondary is equal to the product of the primary voltage times the current and divided by the current in the secondary. Hence, the equation

$$V_2 = \frac{V_1 \times I_1}{I_2} \tag{75}$$

where, I_1 and I_2 are respectively the currents in the primary and the secondary windings of the transformer.

Example:—A current of 10 amperes at 550 volts is running in a transformer primary. What will be the voltage in the secondary if the current through it is 0.1 ampere?

From equation (75), the secondary voltage is

$$V_2 = \frac{V_1 \times I_1}{I_2} \qquad \text{where,} \quad \begin{aligned} V_1 &= 550 \text{ volts.} \\ I_1 &= 10 \text{ amperes.} \\ I_2 &= 0.1 \text{ ampere.} \end{aligned}$$

$$= \frac{550 \times 10}{.1} = 55{,}000 \text{ volts.} \quad \textit{Ans.}$$

In a transformer, the power input is equal (for practical purposes) to the power output. Hence, the formula (75) may be applied to problems of power transmission.

Example:—The power input in the primary of a transformer is 66 K.W., at 100 amperes and 660 volts. If the transformer constant is 1 :100, what will be the current in the secondary?

Since the tranformer ratio is 1 : 100, the voltage on the secondary coil must be 100 times 660, or 66,000 volts.

Then, according to formula (75), we have

$$V_2=\frac{V_1\times I_1}{I_2} \quad \text{where,} \quad V_1=660 \text{ volts. } I_1=100 \text{ amperes. } V_2=66{,}000 \text{ volts.}$$

or,

$$I_2=\frac{V_1\times I_1}{V_2}$$

$$=\frac{660\times 100}{66{,}000}=1 \text{ ampere.} \quad \textit{Ans.}$$

(c) The induced current in a coil of wire is inversely proportional to the number of turns in that coil. Therefore, the current in the secondary turns is equal to the product of the primary turns times the primary amperes divided by the secondary turns.

$$\frac{I_2}{I_1}=\frac{N_1}{N_2} \tag{76}$$

or,

$$I_2=\frac{N_1\times I_1}{N_2} \tag{77}$$

Example:—The primary coil of a transformer having 200 turns of wire receives a current of 10 amperes. What will be the current through the secondary winding which has 1000 turns?

By equation (77), the current through the secondary will be

$$I_2=\frac{I_1\times N_1}{N_2} \quad \text{where,} \quad I_1=10 \text{ amperes. } N_1=200 \text{ turns. } N_2=1000 \text{ turns.}$$

$$I_2=\frac{10\times 200}{1000}=2 \text{ amperes.} \quad \textit{Ans.}$$

The general equation for the induced electromotive force in the secondary of a transformer may be given as

$$E=N\frac{2\pi f\phi}{\sqrt{2}\,.\,10^8} \tag{78}$$

where, E is the electromotive force in volts having a root-mean square value, N is the number of turns in the winding, f the frequency of the current in cycles, and ϕ is the magnetic flux in maxwells through the transformer core. This formula only holds true for an alternating current having a sine wave form.

8. Direction of Induced E.M.F. In A Conductor.—(*a*) *A Wire Cutting Magnetic Lines of Force*:—The rule for finding the direction of the induced E.M.F. in a conductor placed in a magnetic field is the converse of the right-hand rule. That is, if a wire, placed in a magnetic field, is grasped with the right hand so that the fingers around it lie along the direction of the magnetic field (north to south), the thumb, lying along the wire, will point in the direction of the induced E.M.F. in the wire, as shown in Fig. 57.

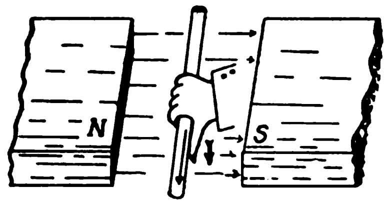


FIG. 57. INDUCED E.M.F. IN A WIRE.

(*b*) *Kirchoff's Law*:—When the thumb, index finger, and the middle finger of the right hand are spread apart so that they are at right angles to each other, if the middle finger lies along the direction of the magnetic field, the index in the direction of motion of the wire, then the thumb will point in the direction of the induced current. The Kirchoff's Law originally applies to motors, but the above is so modified that it can be applied to finding the direction of the induced E.M.F. in a generator armature.

9. The Induction Coil.—The induction coil makes use of the same principles that we have been discussing heretofore. The two coils of the induction apparatus, as shown in Fig. 58, are wound around a common core, each coil insulated from the other. The primary coil has only a few turns of coarse wire and carries relatively more current at less voltage than the secondary coil. The secondary has relatively greater number of turns of fine wire wound on top of the primary and well-insulated from the former, and it carries relatively a low amperage and high voltage—the voltage depending upon the ratio between the number of turns in each coil.

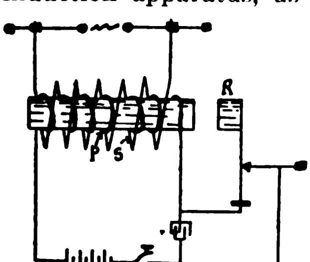


FIG. 58. A TYPICAL INDUCTION APPARATUS.

In the apparatus, shown in Fig. 58, when a current passes through the primary coil P, the iron core inside the coil becomes magnetized, and thus adds its magnetic field to that of the primary, inducing an E.M.F. in the secondary coil S. A soft-iron armature head R is mounted on a flat spring and is connected in series with the primary circuit.

As the iron core becomes magnetized, it attracts the soft iron armature head R, thus breaking the circuit, which again induces an E.M.F. in the secondary. As soon as the circuit is broken, the iron core loses its magnetism and releases R, which springs back, closing the circuit once more. This arrangement will cause the armature to vibrate rapidly with each make and break of the current, increasing and decreasing the magnetic field in the primary. Thus, the increase and decrease of the primary

magnetic field will produce a large induced E.M.F. in the secondary coil.

A condenser, connected in parallel with the primary circuit on the side including the armature, will largely aid the more sudden breaking of the current, thus producing a greater rate of change of flux. Since the current changes more rapidly on the break than on the closing of the circuit, a greater electromotive force will be induced in the secondary upon breaking the circuit in the primary than upon closing it.

The primary circuit, including the iron core and the armature, of the induction coil presents the principle of an electric door-bell. In the latter, however, the armature head is connected to a hammer which vibrates against a metal bell, or some alloy, producing the familiar buzzing sound.

QUESTIONS ON CHAPTER IX

1. (a) Discuss the induction of electromotive forces by a magnet.
   (b) What is the relation of a changing magnetic field to the behavior of the electrons in a conductor?
   (c) Why is it necessary to have a magnetic field or an electric field in order to produce respectively an electric field or a magnetic field in an adjacent conductor?
   (d) Illustrate by a diagram how E.M.F. may be generated in a coil of wire when a current is running in an independent adjacent coil.
2. (a) State the law of induced electromotive forces, and give the formula representing the induced E.M.F. in volts.
   (b) Give Lenz' Law, and express, in a formula form, the E.M.F. relation in terms of inductance and current.
   (c) Explain with a diagram how an induced E.M.F. can be produced by a pulsating direct current. Give the wave curve of the induced E.M.F.
3. A coil of wire, having 200 turns and an effective area of 80 square centimeters (exposed to the influence of the magnetic field), is rotated 90 degrees in 1/4th of a second about its axis in a magnetic field of an intensity 40 gausses. (1) What will be the total lines of force threading the coil? (2) What will be the induced E.M.F.? (3) If the coil has an impedance of 0.20 ohm, what will be the induced current through the coil? (4) Find the inductance of this coil.
4. (a) Discuss the induction of E.M.F. by an alternating current, and give the wave form of the induced E.M.F. and current.
   (b) What is an insulating transformer used for?
   (c) State two laws pertaining the directions of induced E.M.F.'s.
   (d) Draw the diagram of a typical induction coil and describe its parts and operation.
5. A generator having 6000 turns in its armature is connected to the shaft of a motor. The armature is rotated, by the motor, 90 degrees in one second in a magnetic field of 2,000,000 maxwells, and the energy produced is carried to the primary coil of an X-ray transformer. If the transformer constant is 1:500, (1) What will be the effective voltage through the X-ray tube? (2) What current will flow in the transformer secondary if it has an impedance of 30,00 ohms? (3) What will be the power in the primary coil of the transformer?

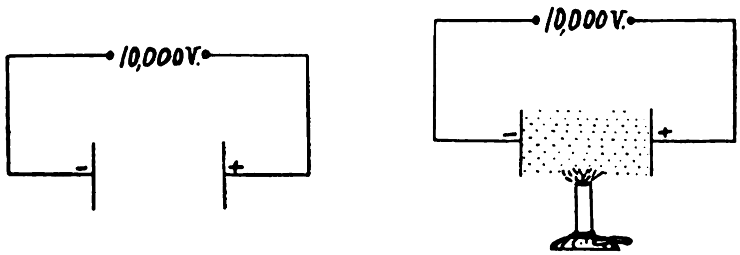
CHAPTER X

DISCHARGE IN GASES, AND VACUA

Part I

Discharge In Gases

1. Discharge Through Gases At Standard Conditions.—When a gas is at 760 mm mercury pressure, and at a temperature between 0° to 20°C., the conduction of electrons through it will depend upon the distance that the electrodes are put apart, and upon the impressed voltage on the electrodes. With a given voltage, the discharge from one electrode to the other will depend upon the distance of the gap between the electrodes—the shorter the gap the greater and faster the discharge will take place. As this distance is increased, the impressed voltage should be correspondingly increased in order to prolong the discharge in the interelectrode space. However, a gas under standard conditions behaves as a poor conductor, and therefore, it will take in the neighborhood of 10,000 volts, or more, for a spark to jump across a gap of 1 cm, while ordinary household circuit voltages will hardly carry a spark to a distance over a few mms.



(A) (B)
FIG. 59. ILLUSTRATING A DISCHARGE UNDER STANDARD CONDITIONS.

If the electrodes in Fig. 59a are put apart at such a distance that the length of the intervening air gap is just beyond that necessary to produce a visual corona, and some outside source of heat, such as from a burning candle, or a bunsen flame, is introduced beneath the air-gap intermediate to the electrodes, the air between the electrodes becomes immediately ionized, forming a continuous disruptive discharge across the gap, as in Fig. 59b. The conduction of the ions in opposite directions and their collisions with the corresponding electrodes produce heat, and cause further ionization of the gaseous medium. The ionization of the air is accompanied by a light of great brilliancy.

The principle of disruptive discharge without the use of an external heat source as mentioned above is made use of in the determination of

high potentials, such as the peak voltage impressed on X-ray tubes. This procedure is routinely followed in the calibration of an X-ray apparatus.

2. Discharge Through Gases At Reduced Pressures.—In Fig. 60, below, is shown a long glass tube G having at each end a sealed-in electrode impressed with a potential from the secondary side of a transformer, or an induction apparatus. A side arm S, fitted with a stop-cock, is connected to a vacuum pump P.

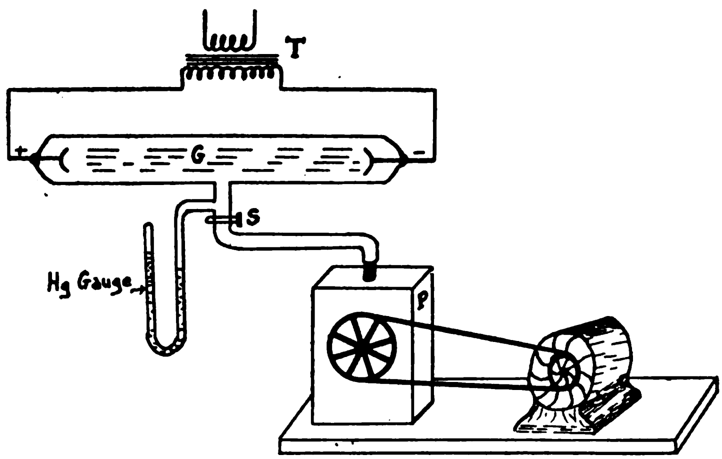


FIG. 60. ILLUSTRATING A DISCHARGE UNDER VARYING PRESSURES.

If the pump is now operated and the stop-cock is opened to the pump, the air within the tube will start to become rarefied. Within a short time, by continued exhaustion, when a certain rarefication of the gaseous molecules is obtained, a continuous discharge will take place between the electrodes. The gas will glow at first with a brilliant pink color, which will fade away gradually as the exhaustion proceeds. When the pressure is reduced to about 1 mm of mercury, the glow will uniformly change into a yellowish color; and, at a pressure of about 0.01 mm, or less, the discharge will appear as a faint greenish glow. At this stage, there occurs in the neighborhood of the cathode an emission known as *cathode rays.* These rays, as they impinge on the glass walls of the tube will cause it to glow yellowish green. When a high degree of exhaustion is attained, the glowing column will entirely disappear, indicating that the number of air molecules is so diminished that there is not a sufficient number of them to become ionized. Consequently, the discharge stops, when, the tube is said to reach a vacuum state.

During exhaustion of the tube, when the internal pressure has become favorable as to cause the air molecules to become ionized under a given applied potential, negative ions will be formed near the cathode and positive ions near the anode. As the pressure gradually decreases, the negative ions will mostly consist of electrons. Being much lighter than the positive ions, the electrons will acquire a much greater velocity and will move with the negative ions in the direction of the potential gradient

toward the anode. The positive ions, having greater masses, will move at a comparatively slower speed to the cathode.

If the applied potential is sufficiently high, the electrons will acquire great speeds, and before they reach the positive electrode, they will collide with the neutral gaseous atoms. Within a fraction of a second a single electron may foster ionization to thousands of other electrons, the magnitude of this ionization depending on the amount of residual gas, on the speed, and hence, on the potential gradient on the electron. Therefore, with a properly chosen pressure in the tube, the conductivity, and hence, the discharge will increase with the impressed voltage, which will increase the energy of the travelling ions.

3. Luminescence Of Inert Gases.—The radiation from an electric discharge at reduced pressures and generally at low temperatures is known as luminescence. Owing to the fact that gases, and vapors of certain solids, radiate light or glow brilliantly when a high potential discharge is sent through them, advantage is taken of this phenomenon in constructing commercial sign tubes.

A sign tube consists of a long glass tubing with a sealed-in copper, or nickel, electrode at each end, and filled with an inert gas, such as Neon or Argon, at a pressure of between 10 to 75 mm of mercury. The potential between the electrodes ranges ordinarily from 2,500 to 15,000 volts.

As the ionizing potential of a gas depends on the atomic number of that gas, Xenon, having the greatest atomic number among the monatomic inert gases, will ionize at a lower potential than Helium, which has the lowest atomic number of that group. Furthermore, Helium, or Neon, giving off radiations having relatively longer wave-lengths, one would expect these radiations to be in the neighborhood of red or infra-red waves, while Argon, Krypton, and Xenon, giving off radiations of shorter wave-lengths, will glow bluish. Practically this is the case. The sign tubes that glow with a red brilliancy are filled with Neon; those that glow blue are filled with Argon, or, with a mixture of Argon and Mercury vapor. In the case of green, or yellow, glow, the dye in the glass tubing together with a proper mixture of the above gases is responsible in obtaining the required luminosity.

Recently, fluorescent discharge tubes have found wide use in commercial advertising and for decorative purposes. A tube of this character contains a thin coating of fluorescent chemical on its inside walls and is filled with a small quantity of inert gas, or mercury vapor. In operation, when the ionized gaseous particles collide with the fluorescent coating, it glows with a characteristic color. By using various types or mixtures of the fluorescent substance, an unlimited number of color schemes can be obtained from the tube.

4. Ultra-Violet Radiations.—When a high tension current is passed through a discharge tube filled with mercury vapor, the radiant vapor will emit rays of light containing ultra-violet radiation ranging from 136 to 3900 Angstrom units. If the vitreous envelope, or the container, of the vapor is made of ordinary glass tubing, the shorter wave-length and high frequency ultra-violet rays will be screened off. Pyrex glass ceases to transmit rays having wave-lengths below 3000 A.U., while

the limit for Quartz is 1500 A.U., and for Fluorite glass about 1250 A.U.

Ultra-violet rays may be produced by any incandescent body, or vapor, such as by a carbon arc, by a disruptive discharge in air, or by a metal kept at incandescence in air. But, due to the inconvenience in the handling of ultra-violet devices of the above character, the quartz tube construction is preferred.

Since the use of ultra-violet rays is becoming more popular with the physicians in treating rickets, sinus disorders, and for sterilizing instruments and drinking glasses, a new industry in the manufacture of cold ultra-violet tubes has started, and is progressing quite rapidly.

Rickets is cured by ultra-violet rays having wave-lengths between 3200—2900 A.U., and also in the neighborhood of 2500 A.U. But, since the ultra-violet radiations shorter than 3000 A.U. are stopped by ordinary glass, quartz tubing transmitting the rays having wave-lengths as low as 1500 A.U. is used in the manufacture of such tubes. At present, most ultra-violet tubes are made of either a quartz, or fluorite envelope.

Before a discharge takes place in the tube, the mercury vapor has to pass through stages of excitation by electron impact, ionization by loss of orbital electrons, and radiation by atomic energy re-arrangement, after which process, the ultra-violet radiation can be detected. This phase, however, will be taken up in the accompanying sections.

Ultra-violet rays can be detected photochemically, by spectroscopy, and by other effects. The most common way of detection is manifested in the blistering of the human skin exposed to this radiation a few minutes at a short distance from the source.

5. Electric Fields.—Whenever there is a potential difference between any two conductors, there exists an electric field; and, as a result work is done. If it is desired to express the field intensity or the potential difference per unit interelectrode space, the term potential gradient is applied.

In the subject of mechanics, work is defined as the product of the force exerted and the displacement (distance) in the direction of the force. For example, if a force of one *dyne* moves through a distance of 1 cm, the work thus accomplished is 1 *erg*. Expressed in the form of an equation, we have

$$W = F \times d \tag{79}$$

where, if F is given in dynes, and d in centimeters, then the work W is expressed in ergs.

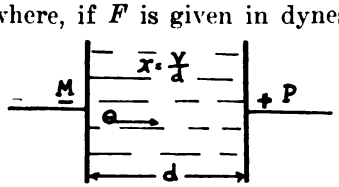


FIG. 61. FORCE ON A CHARGE IN AN ELECTRIC FIELD.

For the determination of the work done by an electric charge moving in an electric field, let us assume a negative charge, or an electron, e, in Fig. 61, travelling a distance d between the two electrodes, denoted by M and P. If the potential applied on the electrodes is V, then the work done in carrying the electron e to the positive electrode is given as

$$W = Ve \tag{80}$$

in which, V is given in electrostatic units of potential, and e is the charge of the electron in electrostatic units, (written e.s.u.).

Since the two quantities represented by equations (79) and (80) are equal, we may equate them as follows:

$$W = Fd = Ve \tag{81}$$

and,

$$F = \frac{V}{d}.e \tag{82}$$

where, V/d is known as the field intensity, denoted by X, and is given in volts per centimeter. Therefore, we may re-write the equation (82) as

$$F = Xe \tag{83}$$

Thus, for an electron moving a distance d in an electric field X, the energy expended will be

$$W = Xe.d \tag{84}$$

and,

$$W = Xe.d = Ve \tag{85}$$

Equating the last two terms of the formula (85), we obtain

$$V = Xd \tag{86}$$

where, V is the applied potential in electrostatic volts on the electrodes.

Since 300 practical volts are equal to one electrostatic volt, the equation (80) may be written as

$$W = \frac{Ve}{300} \text{ ergs.} \tag{87}$$

and,

$$W = \frac{Xde}{300} \text{ ergs.} \tag{88}$$

in which, V is expressed in practical volts, and e is the charge of the electron, or 4.77×10^{-10} e.s.u.

A charge moving in an electric field acquires velocity, and hence, kinetic energy, $\frac{1}{2}mv^2$, which is exactly equal to the work, $Ve/300$, done on the charge during its transfer in the direction of the potential gradient. Thus, by equating these two energy quantities, we obtain

$$\frac{1}{2}mv^2 = \frac{Ve}{300} \tag{89}$$

where, m is the mass of the charge, and v its velocity.

Example:—If an electron moves a distance of 10 centimeters in an electric field of 5 volts per cm., (1) What is the work done on the electron?

(2) What will be the velocity acquired by the electron?

(1) According to equation (88), the work done on the electron is given as

$$W = \frac{Xde}{300} \qquad \text{where,} \qquad \begin{aligned} X &= 5 \text{ volts/cm.} \\ d &= 10 \text{ cms.} \\ e &= 4.77\times10^{-10} \text{ e.s.u.} \end{aligned}$$

$$W = \frac{5\times10\times4.77\times10^{-10}}{300}$$

$$= 7.95\times10^{-11} \text{ ergs.} \qquad \textit{Ans.}$$

Which last value is also the kinetic energy of the electron.

(2) By equation (2), the electron will acquire a velocity

$$v = \sqrt{\frac{2Ve}{300m}} \qquad \text{where,} \qquad \begin{aligned} V &= 50 \text{ volts.} \\ e &= 4.77\times10^{-10} \\ m &= 9\times10^{-28} \end{aligned}$$

$$v = \sqrt{\frac{2\times50\times4.77\times10^{-10}}{300\times9\times10^{-28}}}$$

$$= \sqrt{\frac{100\times1.59\times10^{-10}\times10^{28}}{100\times9}}$$

$$= \sqrt{17.6\times10^{16}} = 4.335\times10^{8} \text{ cms/sec.} \qquad \textit{Ans.}$$

6. The Displacement Of Electrons In An Atom.—It is already stated that an atom at rest is neutral. A neutral atom is stable, as it contains equal numbers of electrons and protons. An equilibrium thus set between the negatively charged electrons and the positively charged protons can not be disturbed without applying energy to the atom from an external source.

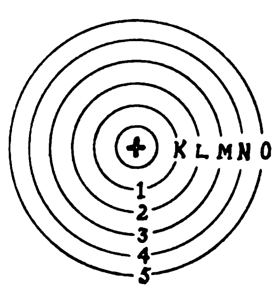


FIG. 62. CHARACTERIZATION OF QUANTUM NUMBERS IN AN ATOM.

In the neutral state of an atom all the extranuclear electrons are in normal motion in their *stationary states* or *orbits*. These *stationary states* are characterized, proceeding along the sequence of orbits from the nucleus outward, by *quantum number* 1, *quantum number* 2, *quantum number* 3, and so on, to the outermost orbit; and, these orbits are also known respectively as *K, L, M, N, O, P*, etc., *levels*. That is, the *K-level* is an orbit of quantum number 1, the *L-level* is one of quantum number 2, etc., as shown in Fig. 62. Hence, when an electron is revolving normally, say,

in the second, or *L-orbit,* then it is said to be occupying the level of quantum number 2; when an electron occurs in the *3rd,* or *M,* orbit, it is then known as an electron of quantum number 3, and so on.

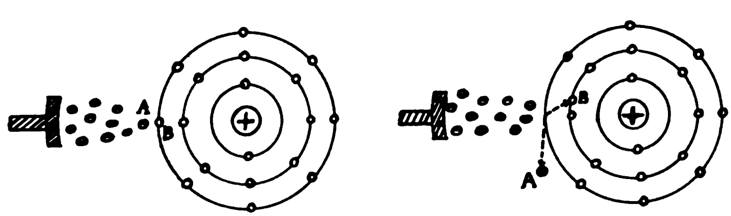
When a gas is rarefied in a discharge tube, and a sufficiently high voltage is impressed on the electrodes, the atoms of the gas acquire a part of the voltage energy. The energy absorbed by the atom is either from the primary electrons emitted from the charged electrodes or from the charged atoms of the same gas. An atom thus disturbed will have one or more of its electrons revolving in an orbit of higher quantum state than the normal, thus increasing the energy of the new orbit; and, the atom is said to be transferred to an *excited state.*

The process of moving the electron from a normal to one of higher quantum level is known as *excitation* of the atom, which requires energy. This energy may be supplied by *collision* with a moving electron which may transfer to the atom a part or all of its kinetic energy, or, the atom may acquire energy from another atom in the process of *thermal agitation.* If the energy received by the atom is sufficiently great as to remove the electron from that atom, the latter becomes *ionized.*

As the excited atom has one or more of its electrons removed to an orbit of higher quantum number, the energy of that orbit increases, with a corresponding decrease in energy in the first orbit. But, an atom having excess of electrons in a given orbit than that orbit can normally retain is in an unstable state. Therefore, the electron normally returns to its original orbit. This transition from a level of higher energy to one of lower energy state causes the electron to give off a quantum of light, called a *photon.*

The energy required to raise an atom to an excited or ionized state depends upon the quantum level from which the electron is displaced. The electrons in the innermost orbits are under a greater influence of the nuclear electrostatic action than those in the outer orbits. Thus, the energy required to displace an electron from the inner orbits of an atom of high atomic number will be over a thousand times that required to remove a valency electron, which is more loosely bound to the atom.

Assuming an electron *A,* in Fig. 63a, collides head-on with a valency electron *B* of an Argon atom. The impact results in the removal of



(A) (B)

FIG. 63. DISPLACEMENT OF AN ELECTRON BY COLLISION.

the electron *B* into an inner orbit, as in Fig. (b), and in the deflection of the colliding electron *A.* The addition of an electron to the inner orbit makes a total of nine electrons in that orbit, leaving seven electrons in the outermost orbit. Thus, the energy of the outer orbit is decreased

while that of the inner orbit is correspondingly increased, raising the atom to an excited state. Consequently, the place of the missing electron in the outermost orbit is taken by any one of the electrons from the inner orbit. But, when an electron makes a transition from an orbit of higher energy, say, E_1, to one of lower energy E_2, it emits a quantum of light, or *photon,* with the difference of energy hf between the two levels. Thus, we have

$$E_1 - E_2 = \text{loss in orbital energy.}$$

and,

$$hf = \text{energy of 1 photon.}$$

then,

$$hf = E_1 - E_2 \tag{90}$$

where, h is called Planck's constant and is numerically equal to 6.55 x 10^{-27} erg-sec., and f is the frequency of the photon. Knowing the frequency of the photon, its wave-length can be determined by dividing the speed of light by the frequency, as given by equation (43).

7. Excitation Potential, and Ionization Potential.—The minimum potential required to raise an atom from a normal to one of excited state is called the *excitation potential* for that particular state of the atom; and, when the potential is just sufficient to remove a valency electron completely out of the atom the voltage energy thus expended is known as the *ionization potential.* Increasing the voltage energy absorbed by the atom may cause the removal of some of the other electrons from the outer orbits, or the kinetic energy of the emitted electron may increase in accordance with equation (1). In still another case, this energy may be expended in the excitation of electrons from the inner orbits, resulting in a radiation from that atom. The energy of the radiation is given by

$$hf = \frac{V'e}{300} \tag{91}$$

where, V' is the excitation potential in volts, e the charge on the electron equal to 4.77 x 10^{-10} e.s.u., h is Planck's constant, and f is the frequency of the radiation.

If $Ve/300$ is the energy applied on the electron, and ϕ is the energy required to extract the electron from the atom, or its work function, then the expelled electron will travel in the electric field with an initial kinetic energy given by

$$\tfrac{1}{2}mv^2 = \frac{Ve}{300} - \phi \tag{92}$$

or,

$$\tfrac{1}{2}mv^2 = \frac{Ve}{300} - \frac{V_1e}{300} \tag{93}$$

in which, V is the applied potential in volts, and V_i is the ionization potential for the atom and is given in volts.

Example:—What will be the kinetic energy of an electron impressed with a potential of 8 volts, if the ionization potential of the atom is 4.32 volts? What will be the velocity of the electron?

By equation (93), we have

$$\tfrac{1}{2}mv^2=\frac{Ve}{300}-\frac{V_1e}{300} \quad \text{where,} \quad \begin{aligned} V&=8 \text{ volts.}\\ V_1&=4.32 \text{ volts.}\\ e&=4.77\times10^{-10}\end{aligned}$$

$$K.E.=\frac{8\times4.77\times10^{-10}}{300}-\frac{4.32\times4.77\times10^{-10}}{300}$$

$$\begin{aligned}K.E.&=8\times1.59\times10^{-12}-4.32\times1.59\times10^{-12}\\ &=(8-4.32)\ 1.59\times10^{-12}\\ &=3.68\times1.59\times10^{-12}\\ &=5.85\times10^{-12}\text{ ergs.} \qquad \textit{Ans.}\end{aligned}$$

Since the kinetic energy, $\tfrac{1}{2}mv^2$, of the electron is equal to 5.85 x 10^{-12} erg, its velocity will be determined by

$$v=\sqrt{\frac{2\times5.85\times10^{-12}}{m}}$$

$$=\sqrt{\frac{2\times5.85\times10^{-12}}{9\times10^{-28}}}$$

$$=\sqrt{1.30\times10^{16}}=1.14\times10^{8}\text{ cms/sec.} \qquad \textit{Ans.}$$

Ionization, which is always the result of the loss of an electron by an atom, may occur by either one of the processes known as *electron impact*, *atomic impact*, or high speed *ionic impact*, with a neutral, or, an excited atom. Of these collisions, *elastic impact* is one in which no transfer of energy occurs between the colliding particles, while in an *inelastic collision* the particles in encounter interchange or transfer energy one to another, resulting in the excitation or ionization of the atom, or molecule.

Table IV gives the ionization potentials and the work functions of a number of elements. It will be noticed that the values of these two factors decrease as the atomic number of the element increases.

Table IV:—Least Work Functions, and Ionization Potentials.

Element	Atomic Number	Ionization Potential (volts)	Work Function (volts)
Sodium	11	5.12	2.09
Potassium	19	4.32	1.76
Rubidium	37	4.16	1.55
Cesium	55	3.88	1.38
Helium	2	24.47	20.55
Neon	10	21.47	16.58
Argon	18	15.69	11.57
Krypton	36	13.94	9.98
Xenon	54	12.06	8.39
Mercury	80	10.39	4.86

Whenever an electron is liberated as a result of an inelastic impact there is always a formation of a corresponding positive ion. It may so happen that the energy absorbed during an inelastic collision may be trapped by the atom, exciting it to a metastable state, from which the atom returns to the normal by the step by step transition of the electron, causing emissions of photons equal in number to the number of transitions made. On the other hand, the metastable state may give rise, by further absorption of energy, to an excitation of a higher state or ionization of the atom. The resulting products are a positive ion, and a free electron, which may acquire energy from the positive field and move on producing more ions by collision with other atoms.

8. The Photoelectric Emission.—The photoelectric effect was first observed by Hertz in his investigation of the potential barriers on a set of spark-gap plates illuminated by ultra-violet light. The result of Hertz' experiments was later confirmed by Hallwachs in that when light was incident on a metallic plate negatively charged particles were given off from its surface, causing it to become positively charged. With the discovery of the electron by Sir J. J. Thomson, in 1897, it is now definitely known that the negative particles emitted from an illuminated metallic surface are photoelectrons.

The photoelectric emission is most pronounced for alkali metals, such as Sodium, Potassium, and Cesium, and for other substances like Barium, Selenium, and Cuprous Oxide. In practice, the metal surface to be made emissive is coated with a thin layer of any one of the above electro-emitting substances, and mounted in conjunction with another electrode in an evacuated glass bulb. An assembly of this character is known as a photocell, or phototube. Most of the present day photocells are filled with a rarefied inert gas, such as Argon, or Neon, whose presence considerably increases the photoelectric current through the tube. In Fig. 61a is shown a commercial form of a photocell, whose activated electrode, or the cathode, contains a thin layer of Cesium, and the tube is filled with an easily ionizable gas, such as Argon.

Fig. 64b presents a schematic diagram of a photocell and its circuit, in which P is a photocell illuminated by a beam of light denoted by *hf*, and the resulting photoelectric current is made to pass through a

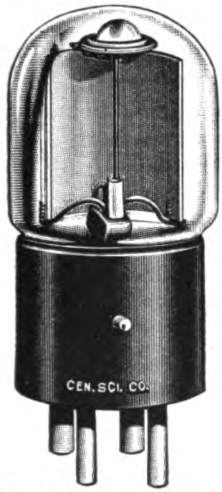


FIG. 64A. A COMMERCIAL TYPE OF PHOTO-ELECTRIC CELL.

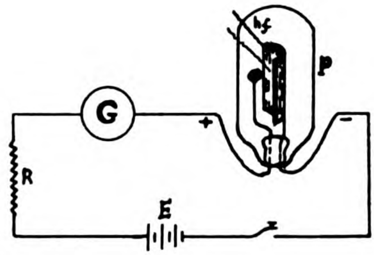


FIG. 64B. CIRCUIT DIAGRAM OF A PHOTOCELL.

galvanometer G connected through a protective resistance R to a source of direct current potential E. The activated electrode of the cell is connected to the negative terminal of the battery, while the other electrode is kept at a positive potential. When the cell is in operation, the photoelectric current will flow from the activated electrode, the cathode, to the anode, or the positive electrode, and the galvanometer will register this current.

By bringing the source of light nearer to the cell, and hence causing an increase in the intensity of the light, more electrons will escape from the activated surface, thus increasing the photoelectric current, as will be evidenced by the increased deflection of the galvanometer.

The energy with which the emitted electron will leave the surface is dependent on the frequency of the incident light quantum. If the quantum possesses a frequency equal to the *"threshold"* or *critical frequency* of the electron bound to the metal surface, then the electron will just be ejected with a zero kinetic energy. On the other hand, if the energy of the incident ray, and hence its frequency, is greater than the one that binds the electron to the surface of the metal, the electron will be released with the difference in energy in the form of kinetic energy, as given by Einstein's photoelectric equation, which is

$$\tfrac{1}{2}mv^2 = hf - \phi \tag{94}$$

in which, f is the frequency of the incident ray, ϕ is the work function of the emitting surface, and m is the mass and v the velocity of the escaping electron. It will be evident from this equation then that the initial velocity, and hence the kinetic energy of the photoelectrons are functions of the frequencies, and the wave-lengths of the incident quanta.

Since the work function ϕ is dependent on the charge of the electron and on the minimum voltage required to remove it from the surface of the metal to which it is confined, we may re-write the equation (94), assigning the quantitative value of ϕ in terms of the voltage energy. Thus, we obtain

$$\frac{1}{2}mv^2 = hf - \frac{Ve}{300} \tag{95}$$

and, introducing the value of the wave-length λ by substituting c/λ for f, we obtain

$$\frac{1}{2}mv^2 = h\frac{C}{\lambda} - \frac{Ve}{300} \tag{96}$$

where, V is the minimum voltage required to liberate an electron from the photo-emissive surface, λ the wave-length of the incident ray in cms., and C is the velocity of light equal to 3×10^{10} cms.

Examples:—(1) What will be the kinetic energy of a photoelectron ejected by a photon having a wave-length of 5×10^{-5} cm., if the work function of the emitting surface is 0.3 volts?

By equation (96), the kinetic energy of the electron will be

$$\frac{1}{2}mv^2 = h\frac{C}{\lambda} - \frac{Ve}{300} \quad \text{where,} \quad \begin{aligned} V &= 0.3 \text{ volt.} \\ \lambda &= 5\times 10^{-5} \text{ cm.} \end{aligned}$$

$$K.E. = \frac{6.55\times 10^{-27}\times 3\times 10^{10}}{5\times 10^{-5}} - \frac{.3\times 4.77\times 10^{-10}}{300}$$

$$= 1.31\times 3\times 10^{10}\times 10^{-27}\times 10^{5} - 4.77\times 10^{-13}$$

$$= 3.93\times 10^{-12} - 4.77\times 10^{-13}$$

$$= (39.3 - 4.77)10^{-13}$$

$$= 34.53\times 10^{-13} = 3.453\times 10^{-12} \text{ erg.} \quad \textit{Ans.}$$

(2) What is the longest wave-length that will release a photoelectron with zero kinetic energy, if the work function of the metal irradiated is 2 volts?

Since the kinetic energy of the photoelectron is zero, then equating the two terms on the right side of the equation (96) to zero, we obtain

$$0 = h\frac{C}{\lambda} - \frac{Ve}{300} \qquad \text{where, } V = 2 \text{ volts.}$$

$$h\frac{C}{\lambda} = \frac{Ve}{300}$$

$$\lambda = \frac{300\,hC}{Ve}$$

$$\lambda = \frac{300 \times 6.55 \times 10^{-27} \times 3 \times 10^{10}}{2 \times 4.77 \times 10^{-19}}$$

$$\lambda = \frac{3 \times 6.55 \times 3 \times 10^{-27} \times 10^{10} \times 10^{10} \times 10^{2}}{9.54}$$

$$\lambda = \frac{58.95 \times 10^{-5}}{9.54} = 6.1 \times 10^{-5} \text{ cm.} \qquad \textit{Ans.}$$

An effective way of increasing the photoelectric current is to fill the cell with an easily ionizable gas, such as Neon, Argon, Krypton, etc. Owing to the fact that the primary electrons liberated from the activated cathode will suffer a number of collisions per centimeter path, some of the gaseous atoms will undergo ionization. The electrons thus liberated, known as secondary electrons, will then accelerate toward the anode liberating other electrons. The process, which is known as *cumulative ionization,* will continue in geometrical progression until the rate of freed electrons equals to that of recombination, when, a saturation point is reached. The photoelectric current then becomes uniform for that particular impressed potential, light flux, gas pressure, and the temperature of the tube.

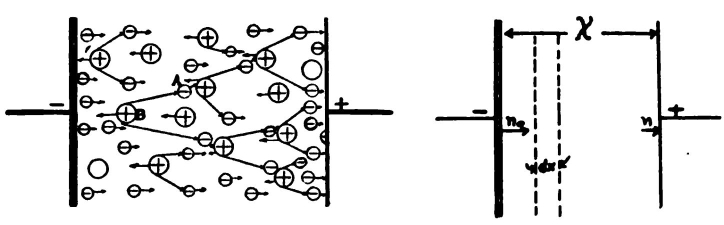


FIG. 65. CUMULATIVE IONIZATION IN GASES.

The condition of electron multiplication is shown diagrammatically in Fig. 65a, in which, an electron A just freed from the emissive surface of the cathode causes an outer electron to be released, by an inelastic collision, from the first atom B of encounter, which later proceeds toward the cathode. The two now free electrons, acquiring kinetic energy from the electric field move on making other collisions, releasing successively one electron after another and producing additional positive ions, and finally lodging on the anode, from which they are carried away as photoelectric current.

The increase of electrons due to cumulative ionization may be calculated when the pressure for maximum ionization, the ionization po-

tential, and the distance between the electrodes are known. For a uniform electric field between two parallel plates, as shown in Fig. 65b, assume that n_0 is the number of electrons released per second from the illuminated cathode M, and n is the number of electrons arriving at the anode P per second. If we designate the number of electrons produced per centimeter path by a, then the number of electrons produced per electron in distance dx will be $a.dx$. Thus, the increase in number of electrons in passing the distance dx will be $na.dx$, or

$$dn = na.dx$$

and,

$$\frac{dn}{n} = a.dx \tag{97}$$

Integrating equation (97) from one plane of the gas column dx to the other, we obtain

$$\int \frac{dn}{n} = a.dx + C$$

where C is a constant taken as the exponent of the *Natural* or *Napierian base* of *logarithms,* and is equal to $log_{nat.}$ of n_0.

When $X = 0$, then $n = n_0$; and, we can equate

$$log\ nat.\ n = aX + log\ nat.\ n_0$$

$$\text{where, } log\ n - log\ n_0 = \frac{log\ n}{log\ n_0}$$

Hence,

$$Log \frac{n}{n_0} = aX \text{ and, } \frac{n}{n_0} = \epsilon^{ax}$$

or,

$$n = n_0 \epsilon^{ax} \tag{98}$$

in which ϵ stands for the *Napierian base of logarithms,* and a is generally known as the *coefficient of ionization* for the particular gas atom.

Since the photoelectric current is directly proportional to the number of photoelectrons n arriving at the anode, we may express the equation (98) in terms of the saturation current I. Thus we have

$$I_0 \propto n_0 \qquad \text{and} \qquad I \propto n$$

Therefore,

$$I = I_0 \epsilon^{ax} \tag{99}$$

where, I_0 is the initial current at the cathode, and I is the total photoelectric current flowing through the circuit.

From equations (98) and (99), it will be obvious that if we increase a, by introducing gas at an optimum pressure for maximum ionization, the secondary electrons, and hence the photoelectric current, will increase to a maximum due to increased number of collisions. Moreover,

increasing the interelectrode space X may accomplish this purpose, but it is not preferred in practice.

The current output of the most sensitive photocell is of the order of 150 micro-amperes per lumen of light, and many ordinary types of cells may yield less than a micro-ampere per lumen*. It is quite obvious then that currents of such magnitudes are incapable of operating any device that is intended to be of any practical use. It then becomes quite necessary that such currents be amplified considerably before they can be of value to a practical extent.

The amplification of the photoelectric current may be accomplished by introducing in the photoelectric circuit a three-element thermionic tube, which functions as an amplifier. A simple circuit diagram of the photoelectric amplification is given in Fig. 66, in which, C is a photo-

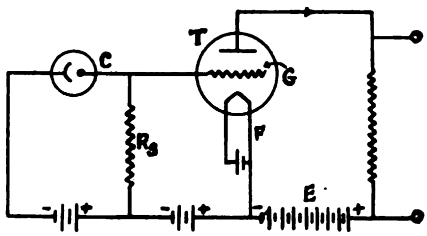


FIG. 66. CIRCUIT DIAGRAM OF A PHOTOELECTRIC AMPLIFIER.

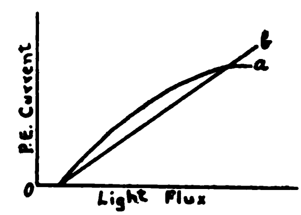


FIG. 67. GRAPH SHOWING RELATION OF LIGHT FLUX TO PHOTOELECTRIC EMISSION.

cell whose anode is connected to the grid G of an amplifier T impressed with a potential in the neighborhood of 100 volts from a direct-current source E. A resistance R_g of several megohms furnishes the proper voltage drop for biasing the grid, which controls the output current.

In practice, the filament F is heated to the required temperature for emitting electrons which are drawn to the plate P held at a positive potential. The number of electrons arriving at the plate is controlled by the magnitude and the polarity of the grid potential, which, in turn, depends upon the variation in the photoelectric emission. Therefore, by varying the voltage on the grid the rate at which the electrons arrive at the plate may be varied. In this respect, the grid becomes a modulating electrode, and that a change in the grid voltage will cause a corresponding change in the plate current. Since the grid is much nearer to the thermionic filament than is the plate, variations in grid voltage become more effective than when the plate voltage is made to effect these changes. Thus, by making the load resistance of the photocell, say, several hundred megohms, current amplification of the order of several million may be obtained from the system.

Fig. 67 shows a photoelectric emission graph, in which the curve (a) represents the relation between the impressed voltage and the photo-

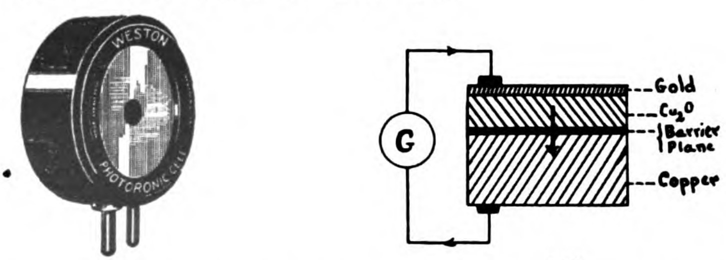
*The quantity of light flux incident each second on one square foot of screen placed 1 foot from a point source of one candle luminous intensity is called a lumen.

electric current, and the curve (b) illustrates the uniform variation of the photoelectron emission in direct proportion to the light flux, or intensity. As will be observed from the chart, the emission current starts a short distance away fom the zero point, indicating that a corresponding amount of light energy is absorbed in the liberation of the first photoelectrons.

The modified plate current from the amplifier output may be utilized in actuating a relay, in facsimile transmission, in recording the smoke content of the air, in reproducing sound from the sound recordings on the margins of movie films, in controlling traffic signal lights, in photometry, in television, in automatically counting and sorting of articles of mass production, and in a variety of other purposes dealing with other phases of manufacturing, and advertising.

9. The Photovoltaic Cell.—A photovoltaic cell is a device which converts the incident quantum energy directly into an electromotive force. This is accomplished by the immediate ejection of photoelectrons as a result of quantum absorption by the photo-emissive surface.

The cell consists of a plate of Copper coated with Cuprous Oxide in intimate contact with a thin layer of Gold or Copper sputtered over the oxide. Thus the metals on each side of the oxide surface constitute the electrodes of the photoelectric circuit. A cell of this character generates its own current and electromotive force, and it can be made in a small unit for conveniently being carried around even in a vest pocket, since no cumbersome connections or batteries are needed for actuating the device. A slightly modified type of this cell has an iron-selenium photo-emissive surface; and, another form is commercially known as the Weston Photronic Cell. It is rated to produce a current of 1.4 micro-amperes per foot-candle of light intensity, or 80 micro-amperes per lumen. The cell is shown in Fig. 68 (a).



(A) (B)

FIG. 68. (A) IS A WESTON PHOTRONIC CELL, AND (B) IS THE CROSS-SECTIONAL VIEW OF A CUPROUS OXIDE CELL.

Fig. 68 (b) represents a cross-sectional view of a Cuprous Oxide cell. The current output of a cell of this type ranges from 50 to 150 micro-amperes per lumen. Owing to the fact that Cuprous Oxide offers a considerably larger resistance for the passage of current from the oxide to the copper than in the opposite direction, the structure may be applied for rectifying alternating currents. The effect is characterized by the localization of an interface between the boundaries of the mother copper and the oxide crystals. This surface of separation between the

two layers is frequently referred to as a *"barrier plane"*, which is largely responsible for the action of Cuprous Oxide when used as a photocell. We shall have further occasion to study the function of Cuprous Oxide in the rectification of alternating currents, especially in X-ray circuits.

Part II

Thermionic Emission

1. Discharge In Vacuum.—In the preceding sections, discharge was treated as taking place in rarefied gas. But, there are cases such as existing in radio tubes, vacuum tube rectifiers, amplifiers, X-ray tubes, etc., in which the presence of any residual gas is a serious handicap in attaining the highest efficiencies from these tubes. To overcome such a disadvantage of the gas tube, high vacuum tubes are resorted to.

When a glass tube is highly evacuated so that no electric discharge can pass between the electrodes placed apart within a discharging distance, and impressed with a relatively high voltage, if one of the electrodes is now heated to a high temperature while the voltage is being sustained, a discharge will occur across the tube. Increasing the temperature of the discharging electrode together with a corresponding increase in the voltage applied will cause a faster and greater discharge.

This phenomenon is further explained in the fact that the free electrons in a metallic body at rest possess a normal distribution of heat motion, which, when disturbed, as by an external application of heat, causes the energy of the electrons to become so great that some of them will actually escape from the atoms to which they are confined. The number of the escaping electrons will increase with rising temperatures; and, when a potential is applied, the electrons will acquire a velocity in proportion to the impressed voltage and will move in the direction of the positive electrode. In a vacuum tube, the electrons will travel from the heated filament to the relatively cooler anode.

The effect of the application of an electrical potential is to impress a definite average velocity of drift on the electrons in the direction of the voltage gradient. This drifting of electrons constitutes the current across the tube and is a function of the applied voltage. The velocity with which an electron will arrive at the plate is dependent upon the impressed voltage on the electrodes and may be computed from the following equation:

$$v = 5.95 \times 10^7 \sqrt{V} \tag{100}$$

where, v is the velocity of the electron due to the applied voltage V.

Before an electron can escape from the surface of a heated filament it must first acquire sufficient energy to overcome the boundary force which exists at the surface of the emitting metal. If the electron overcomes this force and detaches itself from the surface, it induces in the metal a

corresponding positive charge, which is known as the *mirror-image* of the electron and tends to draw the electron back to the surface. But, as the electron recedes, this attraction force decreases in accordance with Coulomb's Law of electric charges, until finally it is freed from the electrostatic influence of the filament surface. The energy required to just remove the electron from the emitting surface is called the *thermionic work function* of that metal.

The magnitude of the electric current established by the number of escaping electrons per square centimeter of the surface area of the heated filament is given by Dushman's equation:

$$I = A_0 T^2 \epsilon^{-\frac{b_0}{T}} \tag{101}$$

where, I is the maximum current in amperes for the particular absolute temperature T of the cathode, A_o is a universal constant equal to 60.2 for all pure metals, ϵ is the base of natural logarithms, and b_o is a constant equal to $\phi e/K$.

In the expression $\phi e/K$, ϕ is the work function of the metal, e the charge on the electron equal to 4.77×10^{-10} e.s.u., and K is Boltzmann's constant having the value R/N, where R represents 8.314×10^{7} ergs per mole per degree, and N is Avogadro's number, 6.064×10^{23}.

Table V, below, gives the values of b_o and the thermionic work functions for different metals.

Table V:—Thremionic Work Functions, and Values of b_o For Different Metals.

Metal	$b_0 = \frac{\phi e}{K}$	Work Function ϕ (volts)
Calcium	35,000	2.42
Cesium	21,000	1.81
Molybdenum	51,500	4.44
Tungsten	52,400	4.52
Thorium	38,900	3.35

2. The Thermionic Saturation Current.—The current through a vacuum tube depends upon the number of electrons discharged per second. With a given filament temperature, increasing the voltage will increase the current up to a point beyond which an increase in voltage will not appreciably affect the emission of the electrons, and hence the current magnitude, since almost all the electrons liberated from the filament are carried to the anode as fast as they are emitted. The point at which this latter effect is observed is called the *saturation point* of the electron emission, and the current thus flowing is known as the *saturation current* for that particular filament temperature. Thus, the saturation current primarily varies with the temperature of the cathode filament, while the voltage only affects the speed of the emission electrons at saturation.

With a given impressed voltage V, the saturation current between two parallel plates is given by the formula derived by Langmuir:

$$I_{max} = \frac{\sqrt{2}}{9\pi} \cdot \sqrt{\frac{e}{m}} \cdot \frac{V^{\frac{3}{2}}}{X^2} \quad \text{amperes.} \tag{102}$$

in which I_{max} is the maximum current per square centimeter of the emitting surface at a given filament temperature, X is the distance between the electrodes, and e is the charge and m the mass of the electron.

The practical significance of the saturation current lies in the fact that current rectifiers, due to their design of construction, allow an unlimited amount of current and hence they should be operated below the saturation point of the current, yet at a higher temperature than the X-ray tube filament, indicated as at region AB′ in Fig. 69b. On the the other hand, X-ray tubes are always operated at saturation currents, beyond the point B, since these tubes require a constancy in current, for a given radiographic technic, with wide variation in the applied potential.

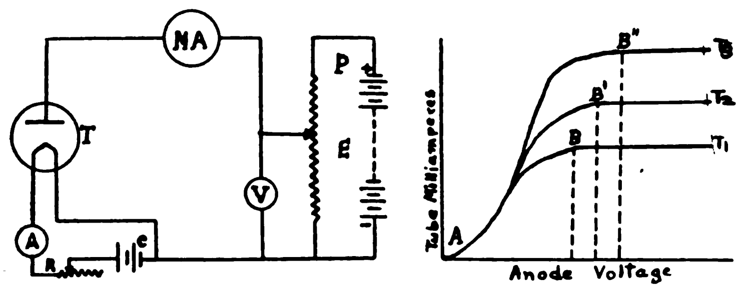


FIG. 69. THERMIONIC CHARACTERISTICS OF A HIGH VACUUM TUBE.

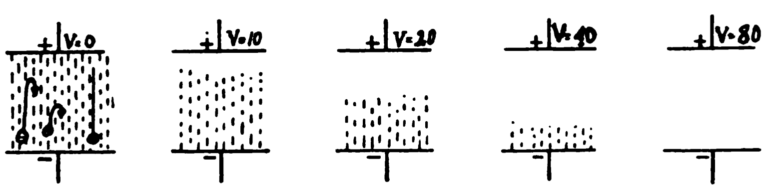
In Fig. 69a is represented the circuit diagram of a two-electrode tube, in which T is a rectifier whose filament is heated by an independent current source C regulated by the rheostat R. The negative terminal of the voltage divider P is connected to the negative side of the filament circuit, while the anode of the tube is held at a positive potential by being connected, through a milliammeter (MA), to the positive terminal of the voltage divider.

If now the values of the anode current (milliamperes) be plotted against the corresponding values of the impressed voltage by varying the latter while the filament temperature is kept constant, for instance, at T_1, a curve as shown in Fig. 69b will be obtained.

It will be noted from the curve (b) that with different values of the filament temperature, such as T_2 and T_3, the corresponding saturation points occur at higher current values with increase in voltage. It should now be clearly understood that any variation in voltage energy beyond the saturation point of a given tube current will only affect the speed of the electrons arriving at the anode, and hence the operation of the X-ray tubes at saturation currents.

3. Space Charge Effect In A Vacuum Tube.—We have already seen how the electron emission from the cathode surface is limited by the boundary force tending to impede the escape of the electron. Now, a second effect, which dictates the transfer of the number of escaping electrons to the anode, is the limitation imposed by the inter-electrode *space charge* constituted by a cloud of electrons at random motions, producing an electric field having a changing potential distribution. The density of this cloud is maximum near the cathode but gradually diminishes toward the anode, where the electrostatic field due to the cathode becomes weak or disappears altogether. The velocity of the electrons then continuously increases towards the anode by the accelerating electric field.

Since only those electrons that have sufficiently great velocities due to their initial energies will reach the anode when at no potential, and since the number of such electrons is small, the current flow through the anode will correspondingly be small. In order to increase the magnitude of this current a large number of electrons must be transferred from the cathode to the anode by an impressed voltage; and, to obtain the maximum current for a given cathode temperature, the positive potential on the anode should be so increased as to draw all the electrons from the cathode as fast as they are emitted. The decrease of space-charge effect by an increase in potential in arbitrary steps is illustrated in Fig. 70, in an exaggerated manner, the shaded areas corresponding to the magnitude of the space charge.



(A) (B) (C) (D) (E)

FIG. 70. DIMINUTION OF SPACE-CHARGE BY INCREASE IN APPLIED POTENTIAL

It will be observed in (a) that in the absence of an accelerating field (with no voltage) only a few of the higher velocity electrons will reach the anode by moving against the retarding field of the cathode and of the space-charge, while those moving with slower velocities will return to the cathode. But, as soon as a small potential is applied, as in (b), and hence an electrical field is established between the two electrodes, the number of electrons drawn to the anode will markedly increase. Further increase in voltage, as in (c) and (d), will result in further decrease in the space-charge, as represented by the magnitudes of the shaded areas, until at higher potentials the effect will practically disappear, as in (e), when, the emission current will reach its maximum value. At this stage, if it happens that the rate of electron emission is just equal to that of its thansfer to the anode, then the potential distribution of the electric field between the electrodes will vary linearly in such system as where the electrodes consist of two flat plates placed parallel to each other, as

shown in Fig. 70. That is, the distribution of potential at the anode will be a maximum, at midway between the electrodes it will be one-half, and at the cathode, the distribution will reduce to a minimum. Hence, a constant potential gradient will be retained throughout the entire inter-electrode space.

Further discussions on space-charge will be found in the chapter on X-ray tubes. Here, we observe that the factors with which we have been confronted elsewhere, in the minimizing of the space-charge effect by our resorting to adequate tube designs or to an increased potential gradient, have become of little significance with X-ray tubes, since these tubes are energized at voltages of 35 kilovolts or higher.

4. Thoriated Tungsten Cathodes, and Oxide-Coated Cathodes.—Up to this time we have only considered the thermionic emission characteristics of pure metals, especially tungsten filament-cathodes. A glance at Table V will convince us that metals, such as Cesium, Calcium, and Thorium, having lower work functions, are far superior to Tungsten as electron emitters. But, in choosing an emitter, other factors aside from efficiency of emission enter into consideration. Cesium, for example, will emit over a thousand times more than that obtained from Tungsten. However, the vapor pressure of Cesium is very high, its melting point is of the order of room temperature, and its mechanical strength is very low. It is obvious then that Cesium can not be drawn into a filament form to be used in place of Tungsten; and, such is also the case with Calcium, Barium, Strontium, or Thorium. On the other hand, Tungsten, having a melting point of 3370° centigrade, may be operated at temperatures as high as 3000°C or over to furnish large electron currents, though its efficiency of emission per watt of heating energy may be markedly low. Accordingly, when Tungsten, having a high melting point and good mechanical strength, is used in conjunction with another metal of high electron emission characteristic at low temperatures, the combination makes an excellent thermionic cathode having an efficiency ranging from 200 to 1000 milliamperes per watt. Examples of this are the *thoriated tungsten* filament, and the *oxide-coated* cathodes.

The thoriated tungsten filament consists of a thin layer of thorium absorbed into the tungsten filament, forming a crystal about the tungsten core. A filament of this type possesses all the properties of a good electron emitter together with the advantages of mechanical properties of tungsten. At 2000°C, a condition much lower than the efficient emission temperatures of pure tungsten filament, the thoriated filament will yield about 2.86 amperes per square centimeter of cathode surface, approximately 3000 times that produced by pure tungsten at the same temperature.

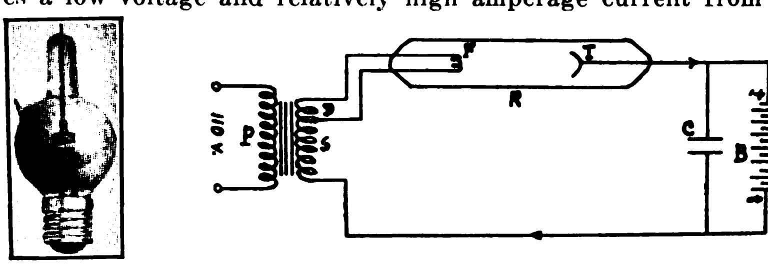
In 1905, in the course of his investigations of the cathode potential drop in discharge tubes, Wehnelt, a German physicist, observed that when the cathode of a discharge tube was impregnated with an oxide of alkali earth metals, such as Calcium, Strontium, and Barium, the cathode drop was markedly reduced. Further and more recent experiments confirmed that the effect was due to the low *thermionic work functions* of these metals, since ionization at the cathode occured more readily, modifying the drop in the cathode potential. Filaments coated with the oxide

of any one of the above metals emit as much as 1 ampere or more per square centimeter at relatively low temperatures. Hence, they are in extensive use in radio tubes, cold cathode tubes, and glow discharge tubes, in which efficiency of emission is combined with the advantages of operation at comparatively low temperatures.

A simple commercial process for activating the filament consists in dipping the tungsten filament into an aquous solution containing 3 per cent Barium Nitrate and about 2 per cent Strontium Nitrate and then evaporating the water in an atmosphere of Carbon Dioxide at the temperature of boiling water. The process may be repeated through a dozen times or more until the desired thickness of the coating is obtained.

Another method of condensing Barium on the filament is by introducing Barium Azide (BaN_6) into the anode, decomposing it at 100°C, and then pumping out the Nitrogen. The resident pure Barium is then evaporized at 130°C, by high frequency induction, onto the tungsten filament which is previously electrodeposited with copper and oxidized.

5. Current Rectifiers.—The characteristic phenomenon presented in the unidirectional flow of thermionic currents in a vacuum tube may advantageously be utilized in the rectification of alternating currents. An example of this is shown in Fig. 71 (a), and the circuit diagram of a rectifier in use is given in (b), in which the primary P of a step-down transformer is connected to a 110-volt alternating current source, and the voltage from the secondary winding S is impressed on the rectifier R connected in series with a battery B. During operation, the filament F receives a low voltage and relatively high amperage current from a



(A) (B)

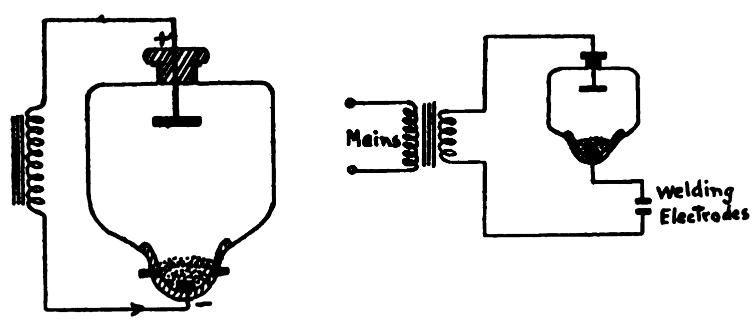
FIG. 71. (A) IS A TUNGAR RECTIFIER, AND (B) IS THE CIRCUIT DIAGRAM OF AN A.C. RECTIFIER.

tapped-in portion D of the transformer secondary. When the filament is heated to incandescence, it emits electrons, which are carried to the anode T by the impressed potential from the secondary terminals. The resulting thermionic current, due to its unidirectionaly flow, charges the battery B during its transit through it. Since this current is pulsating, a condenser inserted in parallel with the battery will aid in smoothing out the ripple to an appreciable extent.

As the cathode F is heated, electrons are emitted only during that alternation when the filament polarity is negative in respect to the anode. Such electrons, therefore, will be discharged from the filament in every other alternation of the current through the transformer secondary. Since the anode temperature is low, no electrons can be emitted from it, and hence the direction of current flow through the tube is maintained

from the cathode to the anode, at which the reverse currents are thus suppressed. The tube, then, will change the current from an alternating current, at the cathode, to an unidirectional, half-cycle, pulsating current at the anode terminal. The process is known as *current rectification.*

The rectifier unit shown in (a) of Fig. 71 is partially filled with Argon to furnish ions so that large currents can be drawn from the tube. A medium-sized rectifier of this type, commercially known as Tungar* rectifier, has a current carrying capacity of about 6 amperes. Larger thermionic units, containing mercury vapor, are built to carry currents as high as 10,000 amperes, and for shorter periods than a second, up to 1,000,000 amperes. One of these rectifiers consists of a mercury cathode, a graphite anode, and a metal envelope, such as iron, that is resistant to the action of mercury, and is insulated from the electrodes by means of porcelain or quartz casings. Power from such rectifiers are ordinarily used in spot-welding. A rectifier of the latter type is shown in Fig. 72a, and a circuit diagram of its operation is given in (b).



(A) (B)

FIG. 72. A LARGE CAPACITY MERCURY RECTIFIER.

In the rectification of high tension circuits, usually vacuum type thermionic units are used. These rectifiers, known under the trade name as *Kenotrons,* (from the Greek word, *kenos,* meaning "empty") are of two types for X-ray use. One type, in which the filament is surrounded with a cylindrical anode, permits large currents with relatively small drop in potential; while the second type is particularly suitable for high tension X-ray circuits by virtue of its filament being positioned at some distance from the semi-concave anode. Since these units allow the passage of current only in one direction, they are generally known as *valve tubes.*

Another method of effecting rectification of alternating currents, having potentials, say, not exceeding 250 volts, is by the use of a Cuprous Oxide rectifier. The construction of this unit essentially embodies that of Cuprous Oxide photocell. We have already seen that when the activated surface of the photocell is illuminated, and the external circuit is com-

*Tungar is a trade name formed by the first syllables of Tungsten and Argon—Tung-Ar.

pleted between the copper and the cuprous oxide, a current will flow from the oxide to the copper. But, when the combination o fthe cuprous oxide and copper is used as a rectifier, the direction of the current flow is just the reverse. That is, the electrons in the latter case can readily pass from the copper to the oxide coating but are unable to flow in the opposite direction due to the considerably increased resistance offered by the cuprous oxide and the barrier plane in the interface between the cuprous oxide and the copper plate. A complete circuit for rectifying an alternating current by cuprous oxide plate rectifiers together with directions of current flow is shown in Fig. 73.

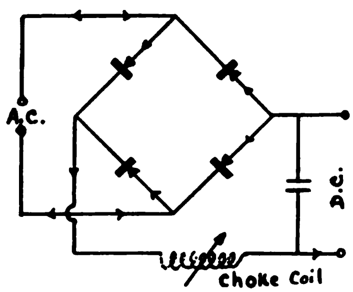


FIG. 73. FULL-WAVE RECTIFICATION BY CU_2O RECTIFIERS.

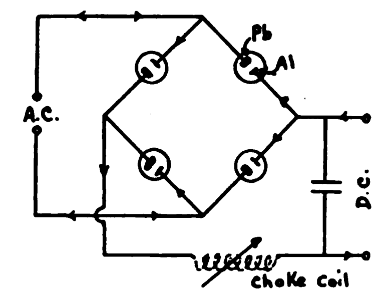


FIG. 74. FULL-WAVE RECTIFICATION PRODUCED BY ALUMINUM AND LEAD PLATES IN SAT. BORAX SOLUTION.

A similar circuit consisting of Aluminum and Lead electrodes immersed in a saturated solution of Borax is shown in Fig. 74. The Aluminum plate serves as the cathode, and after immersion in the solution for a short period, a thin layer of Aluminum Oxide (Al_2O_3) will be formed on its surface. This layer, while readily allows the electrons to pass from the metal to the solution, offers a very high resistance to the reversal of the process. Hence, when an alternating current is impressed on the terminals of such an electrolytic cell, the current will always flow from the aluminum through the solution to the lead electrode, or the anode. Since such a cell will permit only one-half cycle of the alternating current to pass, an arrangement consisting of four of these cells, as shown in Fig. 74, will effect the *full-wave* (full cycle) rectification of the incoming alternations.

It wil be further noted that when these circuits are provided with a choke coil and a capacitance, the pulsations of the output current can be smoothed out. A combination such as this consisting of an inductance and a condenser is called a filter, since it transforms the current impulses into a uniform flow.

6. Comparison of Vacuum Tubes With Gas Tubes.—In comparing a vacuum tube with a gas tube we are mainly concerned with efficiency of output, sturdiness of construction, low cost of manufacturing and maintenance, and long life, of a given tube. Below is listed some of the essential differences in advantages of these two types.

The High Vacuum Tube	*The Gas, or Vapor-Filled Tube*
1. High voltage drop across the tube.	1. Low voltage drop across the tube.
2. Large change in applied potential to produce large current change.	2. Constant applied voltage at various current outputs.
3. Large power loss at the anode.	3. Low power loss at the anode.
4. Current emission up to several amperes per square cm. of cathode surface.	4. Currents up to 100,000 amperes may pass through the tube.
5. Space charge in vacuum prevents current flow across the tube.	5. Space charge is reduced to zero, and current increases by ionization of the gas molecules by collision.
6. Extreme care is exercised in the evacuation and driving all traces of impurities from the tube.	6. Less precautions are taken to completely "dry out" the tube from impurities or occluded gases.
7. The life of a vacuum tube is limited by the rate of filament evaporization.	7. Filament evaporization is reduced to a minimum, and in some designs, the effect is completely eliminated, resulting in longer life of the tube.
8. Current rectification properties are more stable for high tension circuits.	8. Ordinarily, current rectification properties for high tension circuits are less stable, except in highly involved and expensive units.
9. Constant current output with wide variation in the applied voltage.	9. Less constant current output with wide variation in the applied voltage.
10. Vacuum tubes function at higher temperatures, which may be a drawback in certain cases of their use.	10. Gas-filled tubes function at comparatively lower temperatures, thus eliminating the inconvenience curtailed by use of a heated vacuum tube.

Part III

The Cathode Rays

1. The Generation And Nature Of Cathode Rays.—We have already noted in Chapter X that when the pressure of a discharge tube is lowered to 0.1 mm or less and a relatively high voltage is applied, a stream of electrified particles, known as Cathode Rays, are projected from the cathode. The rays produce in the glass walls of the tube a greenish or bluish glow depending on the type of glass used. An object intercepting these rays casts a "shadow", a condition indicating that the cathode rays do not penetrate an object to an appreciably large extent.

Cathode rays are all alike regardless of the kind of gas in which they are produced, or, of the material of the cathode, as in the case of ther-

mionic filament cathodes—an evidence that electrons are the fundamental constituent of all atoms, and matter in general. In a vacuum tube, electrons from the dissociation of the atoms of the cathode metal by the application of heat and potential are made to leave the metal and proceed at great speeds toward the anti-cathode, or the anode. As they impinge on the anode, the kinetic energy of these electrons is transformed to a great extent into heat at the impact, which effect imposes a limitation upon the quantity of power that can be impressed on a given tube. The power loss due to the heat thus produced is practically equal to the amount of power passing through the anode, and is given by the product of the voltage and the amperage.

The kinetic energy of the cathode rays varies as their velocity, which is dependent upon the applied voltage on the tube. The higher this potential the faster the electrons, or the cathode rays, will propagate, as given by the relation shown in equation (100), in which, the velocity acquired by the electron is

$$v = 5.95 \times 10^7 \sqrt{V} \qquad \text{cms/second.}$$

where, V is the applied potential in volts.

Cathode rays have almost innumerable uses in the field of electrical industry. Some of the principal uses of the cathode rays are: When high speed cathode rays impinge on the anode of a vacuum tube they produce X-rays; In radio tubes, cathode rays function as detectors of electromagnetic sound impulses, and as amplifiers and carriers of these impulses through the tube to the loud speaker; Due to their deflectibility by electric and magnetic fields, cathode rays are used in television transmitting and receiving tubes, in which a pencil of cathode beam, whose intensity is controlled by the incoming impulses, is projected on a fluorescent screen and deflected back and forth by the simultaneously impressed electric and magnetic fields surrounding the tube, producing the impression of the broadcast image on this screen. A recently-developed example of the tube is the R.C.A. *Iconoscope*, and the Farnsworth cold-cathode *Cesium-vapor-filled* tube.

2. Properties Peculiar to Cathode Rays.—The following are some of the main properties exhibited by cathode rays:

(1) Cathode rays are negatively charged copious mass of electrons propagating from the cathode.

(2) The mass of a cathode ray particle is equal to that of an electron, 9.03×10^{-28} gram.

(3) Cathode rays propagate in straight lines.

(4) Cathode rays travel at high speeds—from 1/10th to full speed of light, or, from 3,000,000,000 centimeters to 30,000,000,000 centimeters per second, depending on the impressed voltage.

(5) Cathode rays can be focused to a small area by means of electrical fields, or by a concave cathode design.

(6) Cathode rays have kinetic energy determined by the impressed voltage.

(7) Cathode rays generate heat as they impinge on the target metal.

(8) Cathode rays penetrate Aluminum a few centimeters deep.

(9) Cathode rays deflect toward the positive plate in an electric field, and at right angles in a magnetic field.
(10) Cathode rays have slight ionizing power.
(11) When cathode rays impinge upon matter of high atomic number, they produce X-rays, whose penetration qualities primarily depend upon the speed of the impinging electrons.
(12) Cathode rays produce photochemical changes on the photographic film.

QUESTIONS ON CHAPTER X

1. (a) Explain how a discharge can be produced under standard conditions; and under reduced pressures.
   (b) What is luminescence? Discuss its application in industry.
   (c) Discuss the production, ranges of wave-lengths, and the use, of ultra-violet rays.
2. (a) How is an electric field produced? Illustrate by a diagram.
   (b) Two parallel electrodes, placed 20 cms. apart, are maintained at a potential difference of 100 volts. (1) What force will exist between the electrodes? (2) What is the field intensity between the electrodes? (3) If an electron moves 8 centimeters in this field, how much work will be done on it? (4) With what average velocity will the electron travel?
   (c) What distance should an electron cover in an electric field of 5 volts per centimeter in order that it can acquire a kinetic energy of 7.95×10^{-11} erg?
3. (a) Discuss the stationary states of an atom in terms of its quantum energy levels Which stationary orbit gives rise to the lowest quantum energy?
   (b) What quantum conditions must be fulfilled in the excitation of an atom? In the ionization of an atom?
   (c) If an electron radiates during its transition from O-level to L-level in steps, how many photons in succession will be produced? Which photon will have the greatest energy?
4. (a) In an inelastic encounter, an electron radiates with a quantum energy of 5.85×10^{-12} erg. What minimum potential impressed on the electron will incite this radiation?
   (b) What will be the kinetic energy of an electron impressed with 30 volts and liberated from an atom having an ionization potential of 4.16 volts? With what velocity will the electron leave the surface of the atom?
5. (a) Discuss fully the phenomenon of photoelectron emission.
   (b) How is the atomic number of an inert gas related to its ionization potential? Explain, giving a few examples of different gases.
   (c) Show in terms of the intrinsic electrostatic field of an atom how the ionization potential for an alkali metal decreases as the atomic number of the metal increases.
   (d) Define:—Stationary state, quantum number, photon, excitation potential, ionization potential, work function, quantum frequency, threshold frequency, elastic collision, inelastic impact, and lumen.
6. (a) What is a photo-emissive surface? Give some examples of photo-emissive substances, and state what considerations must be taken in choosing a photo-emissive material for a particular photocell construction.
   (b) Draw a simple photoelectric circuit and describe its parts and operation.
   (c) What quantum energy conditions are required before the liberation of a photoelectron? Illustrate this by the incident quantum energy transformation in the atom.

(d) Show with a diagram how cumulative ionization is brought about in a discharge medium.

7. The electrodes of a gas-filled photocell are placed one centimeter apart and maintained at a potential of 100 volts. A photon of wave-length 2.5 x 10^3 A.U. liberates an electron from the Cesium cathode having a work function of 1.38 volts. (1) With what kinetic energy will the electron leave the active surface? (2) What kinetic energy will it have just before impinging on the anode? (3) At what velocity will it arrive at the anode? (4) Find the voltage energy with which the electron is expelled from the Cesium atom.

8. (a) Derive the formula representing the increase of electrons due to cumulative ionization, and give the formula for the photoelectric current.
   (b) Discuss the comparative current outputs of different photocells and their practical applications.
   (c) Draw the circuit diagram of a simple photoelectric amplifier, and briefly describe its operation.
   (d) Show by a graph the influence of light flux or potential on the photoelectric current through a photocell.
   (e) Describe a photovoltaic cell, and give its electrical characteristics.

9. (a) Fully discuss the phenomenon of discharge in a vacuum tube.
   (b) What is the effect of the applied voltage on the speed of the electrons in a discharge medium?
   (c) What factors affect the current to reach a saturation point?
   (d) Of what concern is space charge in a vacuum tube? What conditions cause this effect to become maximum? What conditions favor the reduction of this effect?

10. At what absolute temperature will a tungsten filament having a thermionic work function of 4.52 volts emit a current of 0.125 ampere per sq. cm. of the filament surface?

11. What will be the maximum saturation current produced in a thermionic discharge tube whose electrodes are placed 4 cms. apart and a potential difference of 200 volts is sustained between them?

12. (a) Discuss the significance of thoriating, and oxide-coating the cathode. Describe two methods of coating a cathode.
    (b) Give the general types of current rectifiers, and describe how they operate.
    (c) Draw the Cuprous Oxide rectifier circuit for full-wave rectification of an alternating current.
    (d) Compare a gas-filled rectifier with a thermionic rectifier.
    (e) How are Cathode Rays produced? Give ten properties of Cathode Rays.

CHAPTER XI

THE X-RAY APPARATUS

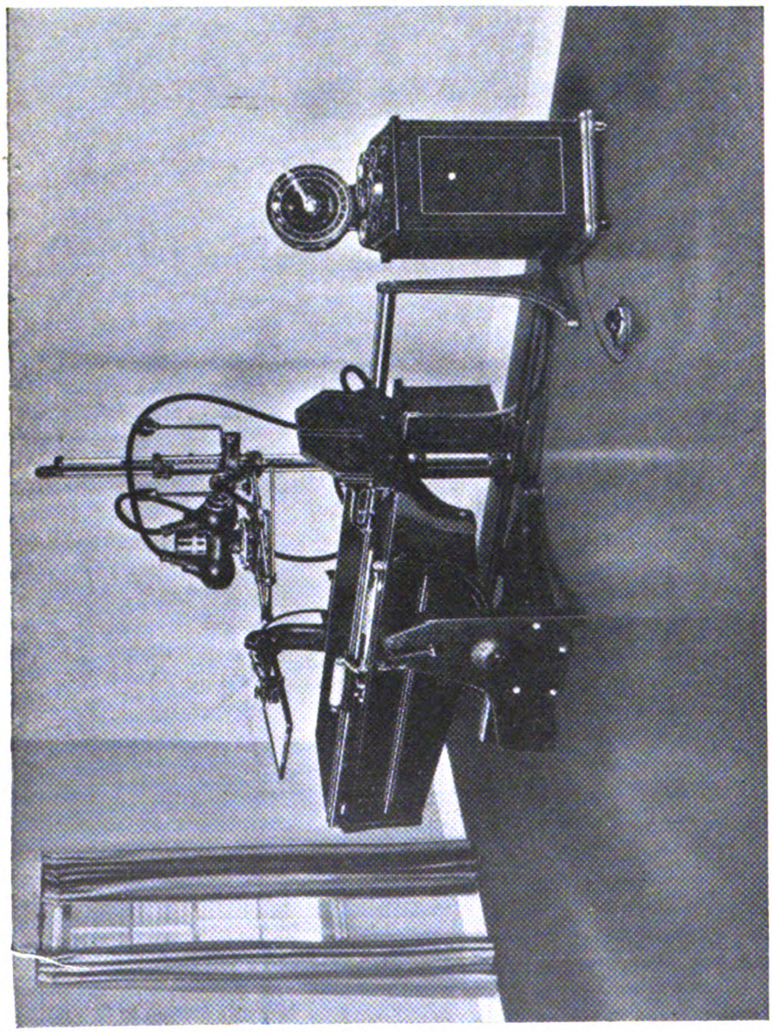
1. A General Discussion On The X-Ray Apparatus.—In order to generate X-rays, it is essential to have a high voltage direct current through the X-ray tube. Since direct current is not ordinarily available at voltages required to produce X-rays, rectified alternating current is generally used. By employing a transformer, the low voltage alternating current is stepped up to a thousand fold and sent through a rectifier which converts it into a pulsating direct current. When this rectified current is allowed to pass from the cathode to the anode of an X-ray tube, invisible radiations known as X-rays are emitted from the surface of the anode.

With modern type of X-ray apparatus, the voltage and the current supplied to the X-ray tube can be accurately controlled and varied independently. The penetrating quality of X-rays can be modified through a wide range by varying the voltage and without appreciably affecting the magnitude of the current through the tube. Conversely, the current through the tube can be varied within wide limitations without affecting the quality of the X-rays. The same apparatus may be used for a variety of classes of service just by changing the accessories and the settings of the controls. The types of service usually expected from an X-ray tube are special research work, radiography of concrete and metal constructions, deep and superficial therapy, and diagnostic work.

Each year new developments and certain physical modifications are made in the construction and design of the different parts of the X-ray machine without a radical departure from the principle on which the machine functions. Such constructional improvements, however, are believed to have been confined primarily to the increased efficiency of the X-ray output, absolute safety to the operator, and substantially longer life of the apparatus, or its parts.

2. Essentials Of An X-Ray Generating Apparatus.—An X-ray generating apparatus essentially embodies a source of 50 or 60-cycle alternating current of about 60 amperes at 110 or 225 volts. Before this power is impressed on the X-ray tube, it is caused to pass through a voltage-controlling device called the autotransformer, which supplies the required voltage to the primary of the X-ray transformer. The high tension current from the secondary side of the X-ray transformer is led to a rectifier mechanism of either a mechanical or an electron tube type; and, after having been rectified, the current is allowed to pass through the X-ray tube for inciting it to emission.

A separate step-down transformer, generally known as a Coolidge filament transformer, receives a small power from a portion of the autotransformer circuit. This power, more commonly taken from the 110-volt alternating current supply line, is controlled by a choke coil before it is impressed on the transformer primary; and, an ammeter placed in series with the choke coil serves to determine the amount of current delivered to the primary coil. The leads from the secondary winding of



(PHOTO—GENERAL ELECTRIC X-RAY CORPORATION)

PLATE I

General Electric Diagnostic Apparatus

(Model R-36)

this transformer, carrying between 3 to 10 amperes at 10 to 12 volts, are directly connected to the filament of the X-ray tube. The magnitude of this current determines the filament temperature and thereby the milliamperes across the X-ray tube. The two windings of this transformer are insulated from each other, by immersion into a mineral oil, to the full voltage of the X-ray transformer.

A current stabilizer, usually placed in the high tension circuit, suppresses any possible fluctuations in the current, thus allowing a steady milliamperage across the X-ray tube. A milliammeter, sometimes incorporated together with the stabilizer, is placed in series with the anode of the tube, and determines the current passing through it during exposures.

In series with the X-ray transformer primary is an automatic timer which is of absolute necessity in controlling the film exposure time. A potential meter, connected across the autotransformer, indicates the potential applied to the primary of the X-ray transformer, and by consulting the pertinent calibration charts the corresponding kilovoltage through the X-ray tube is accurately determined. In most recent X-ray machines, the potential indicating meter is replaced by a kilovoltmeter which registers the actual tube potential directly.

In the case of a mechanically rectified apparatus, a synchronous motor, and a polarity indicator are included. The purpose of the latter is to ascertain, preceding the contacting of the X-ray switch, that the correct polarity of the current through the X-ray tube will be effected when the latter is energized.

Other accessory parts, such as the Bucky diaphragm, the fluoroscope, cones, filters, cassettes, etc. will be taken up in their proper sequence as proceeded towards the considerations of the radiographic aspects of our present scope.

3. The Controls and Indicating Instruments On The X-Ray Panel.— A diagram representing the control panel of a typical X-ray apparatus

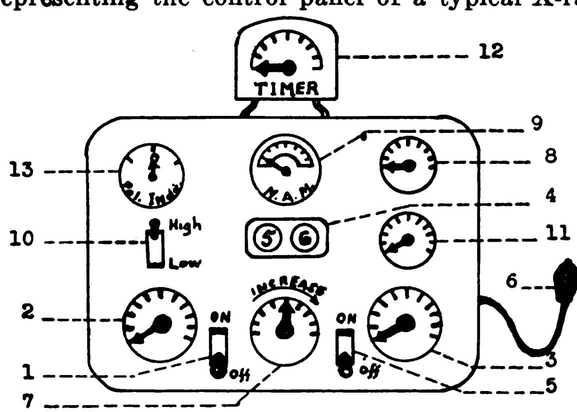
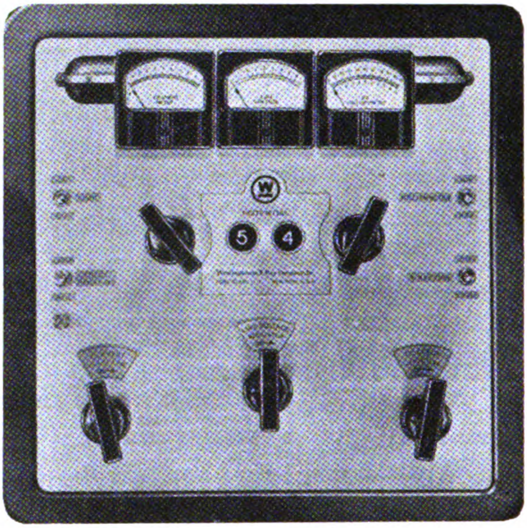


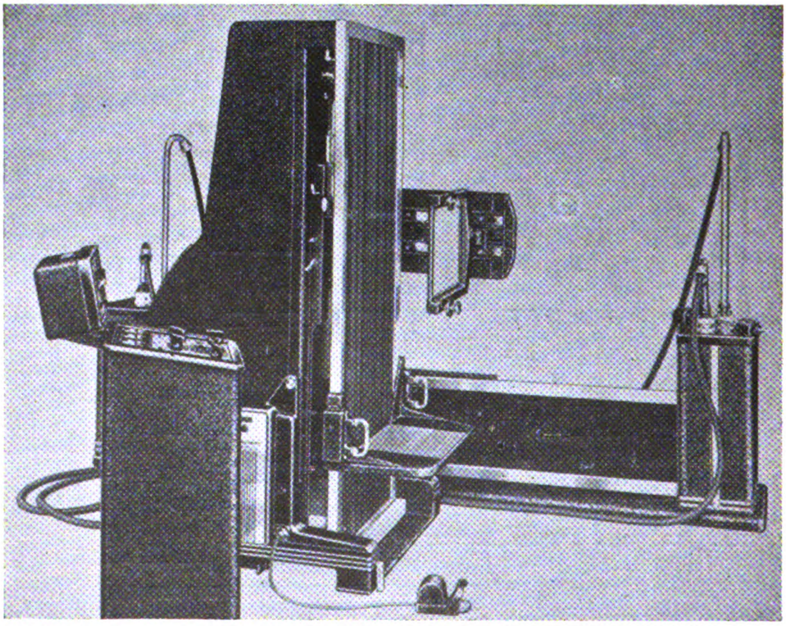
FIG. 75. AN X-RAY CONTROL PANEL.

is given in Fig. 75, in which the main switch (1) controls the primary circuits, and when it is in the "ON" position the filament transformer and the autotransformer are energized, and the X-ray tube is lighted.

Plate II.



Westinghouse Control Panel for 100 MA and 150 MA Generating Units.



(PHOTO — COURTESY WESTINGHOUSE X-RAY CORP.)

Westinghouse Fluoradex-D

Plate II:—Fluoroscopic Examination (Vertical).

If the machine has valve rectification, the filaments of the valve tubes are also lighted in this operation. Now, the coarse adjustment of the autotransformer control (2) may be varied in steps of 10 kilovolts and the fine adjustment control (3) in steps of 1 kilovolt over a range of 10 steps until the desired kilovoltage is obtained, as registered by the numerals at dial (4). This dial indicates the true useful kilovoltage to be impressed on the X-ray tube when the primary X-ray switch (5) is turned to "ON" position. The auxiliary push-button switch (6) is then contacted for exposure. It should be kept well in mind that under no circumstances should the autotransformer controls be adjusted while the X-ray tube is in operation.

Number (7) is a stepless induction type X-ray tube filament control, which offers a smooth regulation of the filament temperature over the entire milliammeter range. To increase the filament current, the control knob must be rotated in the direction of the arrow, and to decrease this current the operation is enacted in the reverse direction. This control may be adjusted even while the X-ray tube is energized, but care should be taken in rotating the knob slowly so that the milliamperage across the tube will not exceed the rated capacity of the tube. The ammeter (8) will indicate the amount of amperage delivered to the tube filament. Indirectly, this meter indicates the exact milliamperage that will pass through the X-ray tube when energized.

The milliammeter (9), which is connected in the high tension circuit on the same side as the X-ray tube anode, indicates the milliamperage passing through the tube during exposures. The instrument may be built together with a current stabilizer in one unit, which, when set to the required milliamperage by actuating a knob, will deliver the exact milliamperage to the X-ray tube.

The scale of the milliammeter varies in calibration from 0 - 60 to 0 - 1000 milliampere for radiography, depending on the type and make of the X-ray apparatus, and from 0 to 15 milliamperes for fluoroscopy. The shunt switch (10) effects the change from one scale reading to the other. In some make of machines this shift from the lower scale to the higher, or vice versa, correspondingly changes the area of the cathode ray impact on the surface of the X-ray tube target.

The resistance control (11), connected in series with the secondary side of the autotransformer, is used only for fluoroscopy and therapy, and it is cut out of the circuit during radiography. Because of the high efficiency of an autotransformer, the use of a rheostat is gradually becoming obviated. A rheostat regulates the power in a circuit at the expense of the dissipation of current in the form of heat, while an autotransformer effects this adjustment by producing a counter-electromotive force in its secondary coil, which regulates the power in relation to the settings made on the transformer controls.

From the X-ray timer (12) any desired exposure time may be obtained within its range. Two general types of this device are now in common use. The synchronous timer, which serves as an accurate time switch, is actuated by an electric synchronous clock mechanism. It has two ranges from 0 to 3 seconds in steps of 1/20th second, and from 0 to 30 seconds in steps of 1/2 second. The second type is an impulse timer. An elegant

timer of this order is theKX-7 unit offered by the General Electric Company. With this timer, exposures as short as 1/120th of a second corresponding to one impulse (½ cycle) of an alternating current wave can be made. It has a range in single impulses from 1 to 24 together with a corresponding scale calibrated in seconds from 1/120th to 1/5th. A precise cam mechanism actuated by a synchronous motor makes and breaks the circuit on the zero point of the current wave, enabling the timer to handle extremely heavy current without danger of arcing or fusing of contact points. During the entire exposure, the X-ray auxiliary switch should be

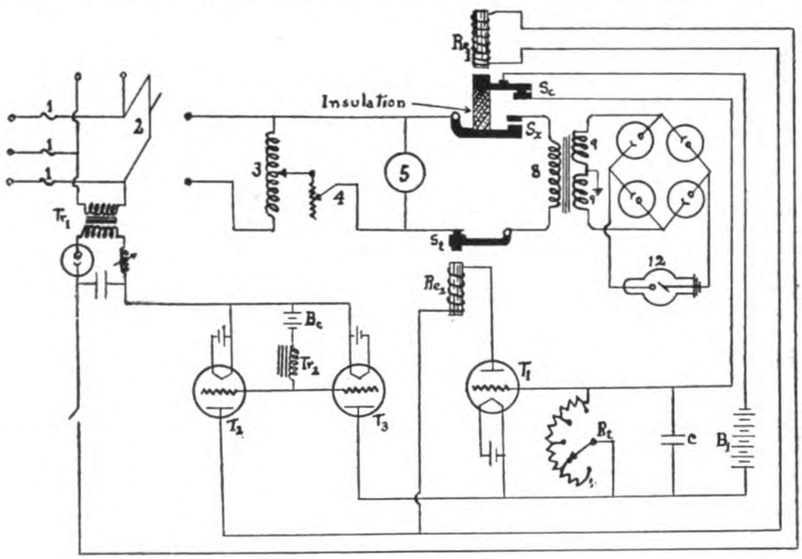


FIG. 76. SCHEMATIC DIAGRAM OF THE IMPULSE TIMER CONNECTED TO THE X-RAY CIRCUIT.

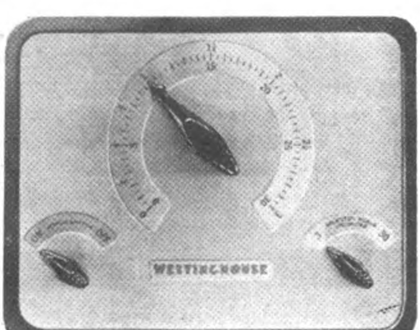


FIG. 77A. THE SYNCHRONOUS MICRO-TIMER.

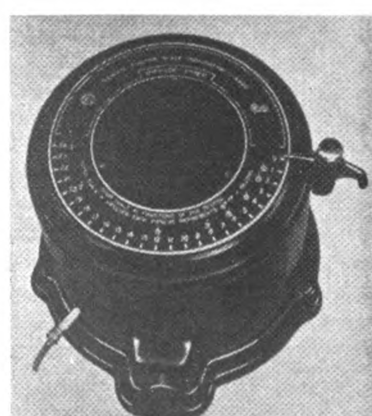


FIG. 77B. THE IMPULSE TIMER.

kept closed until the timer automatically cuts it off at the end of the set time.

In Fig. 76, after the main switch 2 is closed and both the milliamperage and the kilovoltage are adjusted to the required settings, the impulse timer R_t may be set for the desired exposure time by turning the dial knob in the same manner as that on a mechanical synchronous timer. The X-ray push-button is then pressed, which operation energizes the relay Re_1 and closes the X-ray switch S_x in the primary side of the X-ray transformer, thus starting the exposure.

At the same time that the relay Re_1 closes S_x, the switch S_c opens the circuit to the condenser previously charged by the battery B_t, with the result that the condenser begins to discharge through the timer resistor R_t. The value of R_t is so chosen that the time elapsed to lower the condenser potential to the firing voltage of the Thyratron[1] T_1 determines the duration of the exposure. As soon as this voltage is attained, the tube current T_1 passes current which actuates the relay Re_2, and opens the timer switch S_t, thus ending the exposure.

The time for the discharge of the condenser has definite relation to the magnitude of the resistance in R_t. The higher the value of this resistance the longer it will take for the condenser to discharge, and hence it will take a longer time for the condenser voltage to fall to the value at which the Thyratron T_1 becomes energized; and, the converse of this is also true. Thus, by varying the timer resistor (by shifting the pointer to the selected exposure time), any desired time interval within the entire range of the timer may be secured.

The arrangement also makes it possible to open and close the primary circuit of the X-ray transformer at the zero point of the voltage wave. This is accomplished by biasing the grids of the tubes T_2 and T_3 with a negative voltage from a battery B_c to such a value that when this voltage and a small 50 or 60-cycle voltage from the transformer Tr_2 are superimposed and the transformer voltage reaches its peak value the Thyratron T_2 becomes energized. Since the tube T_3 is in series with the tube T_1 and its grid is at the same potential as that of the tube T_2, it (T_3) will allow the tube T_1 to pass current only when the starting voltage characteristics of both of the latter tubes are same. Therefore, T_1 will start in synchronism with the zero point of the voltage wave which pertains the tube T_3.

When it becomes desirable to test the accuracy of the synchronous timer, a device, known as the spinning top, is employed. The spinning top consists of a lead disc (about 5 cms. in diameter) mounted, at its center, on a steel shaft, one end of which fits into a substantial base having a diameter of about 2/3rd that of the disc. Half centimeter from its periphery, the disc has a 2 mm hole. In use, the Top is placed on a loaded cassette and radiographed while spinning. As X-rays are produced in pulsations, a series of dots, whose number is determined by the number of pulsations occuring during the exposure (usually less than one second), are recorded on the film. The number of these dots determines the exposure time.

1.General Electric Three-Element Gas-Filled Thermionic Tube.

A simpler method for checking the accuracy of the timer is to drill a one-millimeter hole through a sheet of lead (8″ x 10″), and, to radiograph the film while pulling the lead at a uniform speed over the exposure holder.

The frequency of the X-ray impulses is dependent upon the cycle of the current energizing the X-ray tube. For instance, for a 60-cycle full-wave anode voltage, the number of pulsations per second will be 120, while for a half-wave current it will be 60. Therefore, an exposure of 1/10th second will consist of 12 dots on full-wave rectification, and 6 dots on half-wave rectification. It will be evident then that any variation in the number of dots recorded other than that calculated for a given exposure time will indicate a condition of inaccuracy in the timer mechanism.

A polarity indicator (13) is necessarily installed on a mechanically rectified X-ray machine in order to ascertain in what direction the current through the X-ray tube will tend to flow when the X-ray switch is closed. The rectification in this machine being effected by the rotation of the synchronous motor in step with the alternations of the current through the rectifier switch, a commutator built on the shaft of this motor permits only one-half cycle of the current to pass through the polarity indicator, which registers either "correct" or "incorrect" according to the polarity of the half-cycle or the alternation caught by the commutator.

When the indicator registers "correct", the direction of the current through the X-ray tube will be, when the X-ray switch is closed, from the cathode to the anode. If the indicator registers "incorrect", a reverse current will tend to pass across the X-ray tube when the switch is closed, and no X-rays can possibly be produced. Therefore, the main switch is turned off, and turned on a number of times until the indicator registers "correct".

In the case of self-rectification, and one or more valve tube rectification apparatus, a polarity indicator is not necessary, since the direction of the current flow thrugh the X-ray tube will always be from the hot cathode to the anode, by virtue of the circuit arrangement of such rectification units. These types of rectificaions, however, will be taken up in detail in the chapter on "Rectification of X-Ray Circuit Current."

4. The Current Stabilizer.—Almost all the latest X-ray machines are equipped with a stabilizer. A stabilizer is a device that maintains practically a constant filament current at any desired value despite any voltage fluctuations in the supply line. For instance, in high milliamperage work, an appreciable line drop of between 15 to 20 volts occurs when the X-ray circuit is energized, with the result that a decrease in filament temperature and hence the tube milliamperage will incur.

Under these conditions, an increase or decrease of 1 percent in the supply voltage may cause correspondingly a fluctuation as high as 20 percent in the tube milliamperage. This condition may be prevented by the incorporation in the filament circuit of either one of the devices known as the *Rieber stabilizer*, and the *Kearsley stabilizer*.

Fig. 78 shows the circuit diagram of the Rieber stabilizer which is essentially a balancing circuit consisting of transformers and automatic choke coils.

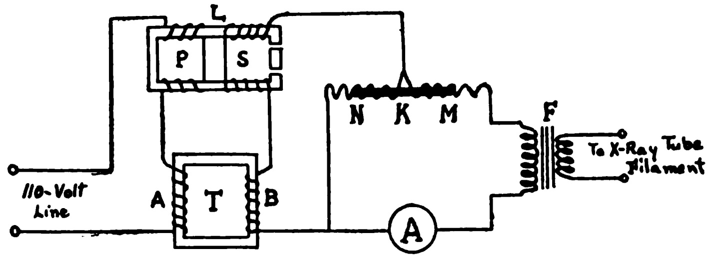


FIG. 78. A SIMPLIFIED RIEBER STABILIZER CIRCUIT.

The primary A of the transformer T, whose core is saturated at a voltage slightly below the supply circuit, is placed in series with the primary winding P of another transformer L, and connected to a 110-volt line. One of the leads from the secondary winding of L is connected to the center of two variable inductance coils N and M at K, and the other lead is made continuous into the secondary coil B of the transformer T. The terminal B is led to the primary of the filament transformer F which is connected to M of the solenoid K. The coil N is then parallel with the filament supply circuit.

Since the core of the transformer T is saturated, the voltage fluctuation in its secondary, B, is considerably reduced, and completely nullified by the relatively small potential in the secondary S of the transformer L, as these two secondary coils are so wound that they produce opposing induced electromotive forces. The air-gap in the core of L is made so as to ensure a counter-electromotive force exactly equal in magnitude to that produced by the fluctuations in the secondary of T, and to nullify this effect.

The current to the primary side of the filament transformer is controlled by the inductance arrangement K, in which there is a movable iron core actuated by gears from the control stand. As this core is slid, say, from M to N, the inductance in M decreases, which condition increases the current to the filament transformer primary.

For technics employing lower milliamperage (under 100 M.A.) the use of a Kearsley stabilizer in the high tension circuit is preferred. The circuit for this stabilizer is given in Fig. 79.

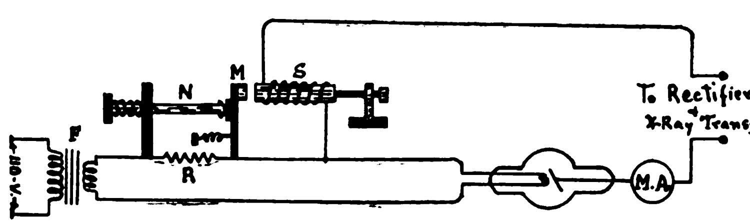


FIG. 79. SIMPLIFIED CIRCUIT DIAGRAM OF A KEARSLEY STABILIZER.

The Kearsley stabilizer maintains a constant milliamperage through the X-ray tube by automatically varying the filament current. That is, any fluctuation in the high tension current causes a corresponding variation in the magnetism of the solenoid S. If the milliamperage passing through the tube is slightly more than that set by the filament control, the spring tension on the armature M will be overcome so that it will be drawn to the solenoid S, thus transferring the path of the filament current through the resistance R, which condition curtails a reduction in the filament temperature and hence the tube milliamperage. The tension of the armature is so adjusted that it will yield to the electromagnet only when the tube milliamperage is in excess of that originally set. If for any reason this high tension current through the tube tends to drop, the armature M immediately establishes a contact with N, short-circuiting the resistance R, and thus raising the filament current sufficiently to prevent the drop. It is obvious then that the armature will have the effect of vibrating back and forth regularly and at the same time cutting the resistance in and out during each impulse of the alternating current from the high tension side of the X-ray transformer, tending to maintain a uniform current through the X-ray tube.

5. The Kenotron Transformer.—In the case of valve-tube rectified X-ray machines, the current to each rectifier, or *Kenotron,* is furnished from a separate step-down transformer, whose primary is connected either directly to the 110-volt line or to a tapped-in portion of the autotransformer winding. A rheostat, or an induction coil should be provided in the primary circuit so that the current to the filament can be varied as desired. To insure longer life, the filament of a *kenotron* should be run at constant voltage and must be sufficiently heavy to supply an electron atmosphere well above that to be allowed through an X-ray tube. Thus, a *kenotron* filament is energized to higher temperature so that at all times a supply of electrons in excess of that produced in theX-ray tube is realized.

Because the secondary winding of the *kenotron transformer* is in electrical contact with one side of the high tension X-ray circuit, the two windings of the *kenotron transformer* must be insulated from each other well above the maximum potential maintained by the X-ray transformer secondary. This is usually accomplished by immersing the transformer in a heavy insulating mineral oil.

6. Technic of Manipulation of The X-ray Apparatus.—When it is desired to operate the X-ray apparatus, the main switch (1) of Fig. 75 is first turned on, which lights the filament of the X-ray tube, and readings will register on the filament ammeter and on the potential indicator (if there is one) of the line voltage. With a given radiographic technic, the voltage is regulated by advancing the autotransformer controls (2) and (3), and the shunt-switch (10) is set on the proper position in accordance with the amount of milli-amperage to be passed through the X-ray tube; e.g., if a current less than 15 M.A. is to be used in the technic the switch is set on the mark *"small"* or *"low"*, and for high current values this button should be set on *"large"* or *"high"*. Now, the filament control (7) is rotated until the desired milliampere setting is obtained on the milliammeter (9); and, finally the timer (12) is set for the required exposure time.

Next, the part of the patient to be radiographed is properly positioned, and the film is placed underneath the part or at a position perpendicular to the X-ray beam and the patient. The X-ray tube is correctly distanced and aligned in respect to the center of the exposure area and the film.

All settings are checked carefully before actually energizing the tube. Special precautions are taken, by using compression bands, or sand-bags, that the patient does not move during exposure. Furthermore, if the tube is not of the shock-proof type, then the operator should see that all parts of the patient are remotely positioned from the ends of the X-ray tube so that no possible spark-over to the patient may occur. Having gone through this procedure, the X-ray switch (5) is turned to the "ON" position, and the auxiliary push-button is pressed and held in that position until the timer automatically opens the circuit upon elapsing of the set time. If desired, similar exposures with the same technic may be made on other films by simply pressing the X-ray button for the exposure; and, exposure settings of other technics may be had by re-adjusting the different controls for the new technic, as outlined above.

When the exposure is made, the X-ray switch, and the main switch are then turned off. The tube stand is rotated to one side so that the patient can conveniently leave the X-ray table. The exposed film is immediately removed from the apparatus and taken to the dark room, or placed in a lead-lined box, to avoid accidental exposure. It is then developed at the earliest convenience of the technician.

7. Calibrating The X-Ray Apparatus.—Practically all late model X-ray machines with valve-rectification system are furnished with factory-determined calibration charts giving information of the power output of the machine under specified loading conditions of the X-ray tube. With a specified milliamperage across the tube, a calibration chart determines the actual kilovoltage delivered to the X-ray tube by the various buttons of the autotransformer.

In the case of a mechanically rectified apparatus, such pre-calibrated schemes are utterly useless, since the matter becomes complicated by atmospheric conditions of the particular location where the X-ray machine is installed; by the manner of adjusting the rotary contactor gaps, and hence the high frequency effect produced during the approach and recession of the contact points of the rotating switch (cross-arm, or disc type); by the condenser effect of the overhead tubings, and thereby a reduction in the kilovoltage delivered to the tube being curtailed. Thus, the X-ray output will vary in accordance with the conditions confronted by the particular machine; and, the issue will further deviate from exponential laws governing the radiographic energy effects. Accordingly, it has become a general practice to routinely chart every mechanically rectified X-ray machine after installation, and to check on these calibrations once or twice yearly, as occasion calls for.

The calibration of the machine is proceeded by first turning on the main switch. This operation actuates the synchronous motor and the transformers, and lights the X-ray tube. The polarity indicator must be carefully checked to see that it points to "*correct*" position, and, if

not, it is caused to assume this position by turning the switch off and on until the correct polarity is obtained, as will be shown on the indicator. All the resistance of the rheostat is now cut out of the circuit, as during radiography, by rotating the rheostat control knob to the highest button, and the autotransformer control may be set to the first button.

Since the kilovoltage readings are taken by the sphere-gap method, it will be advisable to use two spark-spheres each of 5 cms. in diameter. The spark-gap is usually set to a width beyond the distance of a spark-over, and the two leads from the sphere are connected each to one end of the X-ray tube, or they may be attached to the aerials. When all these are properly taken care of, one is in a position to proceed with the calibrating of the machine.

Set the milliammeter to 10 milliamperes, and the aututransformer control to button 1, and turn on the X-ray switch to energize the X-ray tube. Now, cautiously and gradually decrease the air-gap until a spark just flashes over. Stop the spheres at this point, and turn off the X-ray switch. Take the spark-gap readings in centimeters, as given on the graduated scale mounted at the base of the spheres, and then take the readings on the pre-reading potential indicator (which is installed on every mechanically rectified machine). Record these on a data sheet.

Now, widen the spark-gap, switch the autotransformer knob to button 2, and energize the X-ray tube. As previously, take the measurement of the maximum distance at which a spark will be established across the gap. Record this distance in centimeters and the potential readings on the same data sheet under the respective headings. Continue the operation in steps of one button to the highest button; and repeat this with 15 M.A., 30 M.A., 50 M.A., 80 M.A., and 100 M.A. When all the data are taken, the sphere-gap distances are converted into peak kilovoltage values by consulting a spark-gap table such as the one shown in Table VI.

A practical and more or less effective way of checking on the results obtained by the sphere-gap method of kilovoltage measurement is to compare the kilovoltage values secured by sphere-gap with the radiographs made with equivalent voltages by using various thicknesses of Aluminum sheets in comparative respect to Benoist silver disc. That is, each millimeter of Aluminum in comparison with the silver disc produces filterations equivalent to 10 kilovolts. But, this comparison, if made on a mechanically rectified machine, can not be used without modification on a machine having valve-rectification, since the latter type utilizes the entire wave of the alternating current, whereas the mechanical type uses the crests or the peaks of the alternations, with the result that X-rays thus produced are more penetrating.

Whatever the method used in the measurement of kilovoltage may be, if the resulting kilovoltage readings are plotted against the pre-readings of the potential meter, or against the autotransformer buttons, a graph as shown in Fig. 80, below, is obtained.

Table VI:—Sparking Distances for 5 cm Sphere—at 25°C, & 760 mm.

Kilovoltage (peak)	Distance In Cms.	Kilovoltage (peak)	Distance In Cms.
10.00	.29	60.0	2.17
15.0	.44	68.3	2.50
17.1	.50	70.0	2.68
20.2	.60	77.7	3.00
25.0	.77	80.0	3.26
30.0	.94	86.1	3.50
32.0	1.00	90.0	3.94
35.0	1.12	93.4	4.00
37.6	1.20	100.0	4.77
40.0	1.30	106.0	5.00
42.8	1.40	110.0	5.79
45.0	1.50	116.4	6.00
47.9	1.60	126.0	7.00
50.0	1.71	134.0	8.00
52.8	1.80	140.0	9.00
57.4	2.00	145.0	10.00

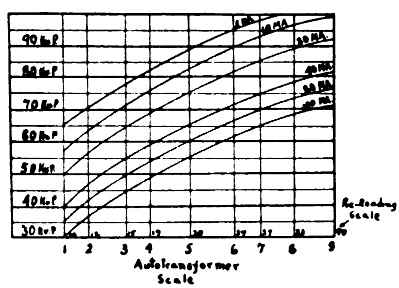


FIG. 80. GRAPH SHOWING KILOVOLTS VS. AUTOTRANSFORMER BUTTONS AND POTENTIAL PRE-READINGS FOR VARIOUS MILLIAMPERES.

A chart of this type should be prepared for every mechanically rectified machine and be kept in the immediate vicinity of the X-ray apparatus in order that the technician may have a ready access to its contents. With a given radiographic technic, the kilovoltage factors can be determined from the chart by first referring to the oblique curve which corresponds to the milliamperage that the technic calls for. This curve is then traced until it intersects the horizontal line drawn from the kilovoltage required in the technic. A perpendicular produced from this point of intersection to the abscissa on the zero line will determine the approximate autotransformer button marked on the abscissa to correspond to the given kilovoltage.

8. Fluoroscopic Procedure.—When a beam of X-rays is incident on certain chemical substances, such as Calcium Phosphate, Barium Platinocyanide, Anthracene, Calcium Tungstate, or Zinc Sulphide, they become

fluorescent with a characteristic glow varying from bluish to apple-green, depending on the chemical used. The intensity of the fluorescence will vary with the amount of radiation. The effect is the result of the transformation of short wave-length X-rays into visible light. If any one of these fluorescent chemicals, say, Calcium Tungstate, is ground into a fine powder and mixed with a binder, and the resulting mixture is applied uniformly on a cardboard support and mounted in a frame covered with lead glass, the assembly offers an elegant means of recording the different densities of the constituent structures of objects traversed by X-radiations. Such an apparatus is called a fluoroscopic screen.

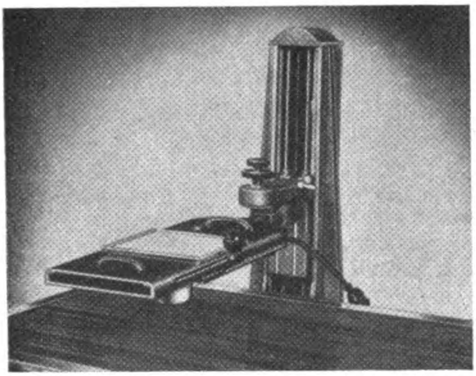
Generally, all X-ray machines are equipped with a fluoroscope. It is mounted on side rails, so that it may be conveniently shifted to any point along the full length of the table over ball-bearing rollers. A shutter-control is detachably mounted on the fluoroscope to regulate the size of the fluoroscopic field during a fluoroscopic examination.

For diagnosis, the patient is interposed between the X-ray tube and the fluoroscope. This may be arranged by rotating the X-ray table to a vertical position and shifting the tube head into position behind the table, from which it directs the rays horizontally through the patient to the screen, as shown in Plate (II). Since both the tube head and the fluoroscopic screen are counterbalanced (at least in most modern X-ray apparatus), the two columns move in unison in their interlocked carriages along the side rail and vertically up and down. If horizontal fluoroscopy is desired, the table is lowered and the patient is positioned horizontally over the table.

Now, the X-ray controls are adjusted by cutting in two buttons on the rheostat control and then turning the toggle-switch to "*low*" position. The milliamperage is set to 5 M.A., and the autotransformer control is adjusted to about 70 kilovolts for a medium-sized person. The kilovoltage may be set to a higher value if the part to be fluoroscoped is comparatively thick. The X-ray push-button switch is disconnected and a foot-switch is plugged in instead, which provides a convenient way of switching the X-ray circuit on and off, enabling the operator to use his hands in adjusting the fluoroscope or the patient to the desired position during diagnosis.

Very recently the Westinghouse manufacturers have developed a fluoroscope attachment, known as *Serialograph*, which combines a fluoroscope and a spot film device into one compact unit. The apparatus may be substituted optionally for the conventional fluoroscopic screen, and is interconnected with the control board to change automatically from fluoroscopy to radiography. For the latter work, the cassette (film holder) is moved into position under the screen, which operation closes a built-in switch, automatically switching the control to the radiographic setting and connecting the timer. The radiographic exposure is then made in the usual manner, except that the foot-switch is used instead of the timer push-button. The advantage of the *Serialograph* lies in the fact that when a certain structure, or position, of the patient's part is spotted during fluoroscoping, a radiographic exposure can be made readily without losing the field by unnecessary delay during manipulation of the

fluoroscope and other adjustments, as would be the case with older methods. Fig. 81 shows a *Serialograph* with compression rack and ratchet.



(PHOTO — COURTESY WESTINHOUSE X-RAY CORP.)
FIG. 81. A WESTINGHOUSE SERIALOGRAPH.

QUESTIONS ON CHAPTER XI

1. (a) What are the essential parts of an X-ray generating apparatus?
   (b) Explain the function of each part in connection with the X-ray circuit.
   (c) Draw the diagram of a typical X-ray control panel and label each part.
2. (a) How are the potential and the current through the X-ray tube pre-arranged? Discuss the technic.
   (b) Differentiate a synchronous timer from an impulse timer. Discuss their circuit connections, and the extent of the usefulness of each.
   (c) How can the accuracy of a timer be tested? Will such a test apply to a timer connected on a constant potential generator? Why?
3. (a) What is the difference between an autotransformer and a rheostat? Which is more efficient as regards power conservation?
   (b) What is a polarity indicator? When is it used?
   (c) Discuss the function of a stabilizer. Draw the diagram of a stabilizer and explain its mode of performance.
4. (a) Explain, why are the kenotron transformer windings insulated from each other to full X-ray transformer tension?
   (b) With a given technic, what mechanical adjustments are made precedent to the making of a radiograph?
5. (a) What significance is held by the calibration of an X-ray apparatus? Discuss the procedure to be had in the calibration of an X-ray machine.
   (b) Give two methods of determining the potential in the high tension circuit of an X-ray apparatus.
6. (a) What is a fluoroscope? How is it used?
   (b) Discuss the action of X-rays on fluorescent substances. How do fluorescent substances radiate visible light?
7. (a) Does the procedure for controlling the power to the X-ray tube during the fluoroscopy differ from that for radiography? Give your reasons.
   (b) What is a serialograph? What advantage does it enjoy over a fluoroscope?

CHAPTER XII

RECTIFICATION OF X-RAY CIRCUIT CURRENT

We have already stated that the conversion of an alternating current to one of unidirectional flow is fundamentally known as rectification. Since a unidirectional current is essential in the energizing of the X-ray tube, the high tension current entering the X-ray tube must necessarily be made to flow from the cathode to the anode before a radiation from the latter is realized.

The rectification may be accomplished by one of the following methods now generally employed: (1) By the X-ray tube itself; (2) By a synchronous mechanical rectifying unit; (3) By Cuprous Oxide rectifying discs, or plates; and (4), By one or more thermionic, or, gas-filled, valve-tubes.

1. Self Rectification—(Half-Wave).—The simplest type of rectification obtained is by means of the X-ray tube itself. In a modern type of X-ray tube, the filament cathode is heated to electron emission, while the anode is kept at comparatively low temperatures. If the electrodes are sustained at a sufficiently high potential difference from an alternating current source, such as from the secondary of the X-ray transformer, the electrons will be drawn from the cathode to the anode only during every other alternation of the curent when the anode is at a positive potential. This permits the current to flow across the tube during the first half of the cycle, whereas the other half cycle is suppressed by the anode when it is negative, and so long as its temperature is maintained below that required for the emission of electrons.

The number of electrons liberated from the cathode determines the magnitude of the current which will flow across to the anode of the tube. Since this emission is dependent upon the temperature of the cathode element, the higher the temperature of the filament the more current will flow through the X-ray tube, and with lower temperatures, the converse is true.

Such an X-ray tube functioning as its own rectifier should be furnished with a cooling system at its anode end in order to carry away the heat generated at the anode by the continuous impact of the electrons. The cooling may be accomplished by employing an anode material of high heat conductivity together with the inclusion of a radiator or of a water-jacket attached externally to the anode stem.

The amount of load that can be carried by the tube is limited. Hence, it should not be used continuously for periods longer than its rated capacity will permit, as it is possible that the concentrated beam of electrons from the cathode by focusing on the focal-spot (area of electron impact on the target) may cause the temperature of the spot to rise to incandescence, setting up an inverse current across the tube, in which case, the life of the tube will be impaired, or may be cut short.

Owing to the fact that the X-ray tube can function as a self-contained rectifier as well as an X-ray generator in conjunction with a step-up transformer, the assembly permits the construction of a very simple and practical portable unit, which may be energized from the nearest electric service outlet of an ordinary household circuit.

The diagram of a simple circuit in which an X-ray tube functions as its own rectifier is shown in Fig. 82. When the secondary of the filament transformer F.T. furnishes a current to the filament of the X-ray tube T, and the electrodes are maintained at a difference of potential from the secondary side of the transformer X.T., the tube will be excited to X-ray emission.

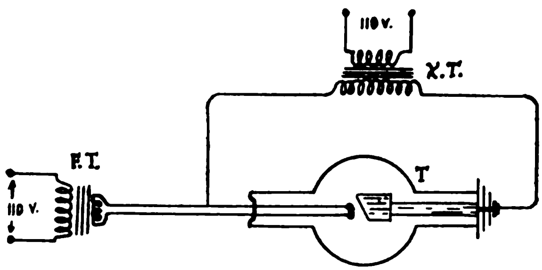


FIG. 82. A SIMPLE X-RAY GENERATOR CIRCUIT.

But, such a circuit as represented in Fig. 82 will prove impracticable for different technics calling for various tube currents and kilovoltages. Therefore, a more feasible circuit including means for controlling the milliamperage and the impressed kilovoltage is one that contains an autotransformer in its primary circuit to regulate the voltage to the X-ray transformer, a filament transformer to control the tube milliamperage, and electrical measuring instruments connected in their respective circuits.

The diagram of a controlled X-ray circuit is given in Fig. 83(a), and the wave form of the current passing through the X-ray tube is represented graphically in (b).

Referring now to the circuit, (1) represents a fuse having a current carrying capacity from 30 to 60 amperes at respectively 110 to 225 volts, and is placed between the mains line and the X-ray circuit to protect the various mechanisms from becoming damaged due to an overload of line current. The main switch (2), when closed, allows the current to flow to the autotransformer (3) and to the filament transformer (15), which is of step-down type. In series with the autotransformer is a rheostat (4) (optional), and in parallel with it is a potential meter (5), which indicates the prereading of the voltage to the primary side (8) of the X-ray transformer.

In the circuit to the primary of the X-ray transformer is placed a timer (6), and in series with it is the X-ray switch (7), which may be replaced by an adjustable automatic circuit-breaker. In the latter case, a push-button mechanism incorporated in the timer may be substituted for the X-ray switch.

One of the leads from the secondary (9) of the X-ray transformer is connected to the cathode of the X-ray tube (12), and the other lead is carried through a milliammeter (11) to the anode of the tube. The secondary (9) is further connected at its center with the ground, as at (10).

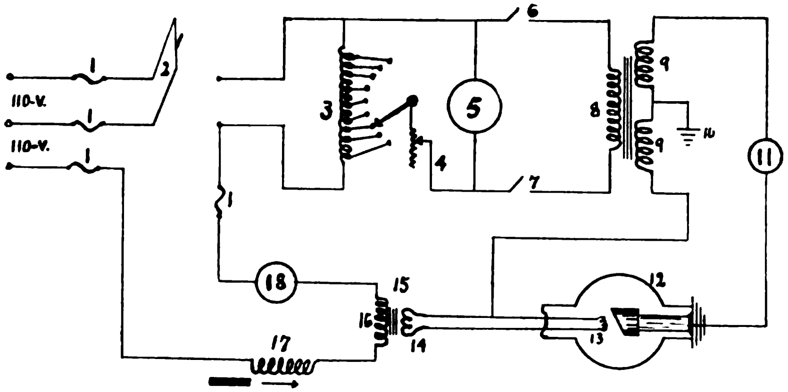


FIG. 83A. A SELF-RECTIFIED X-RAY CIRCUIT.

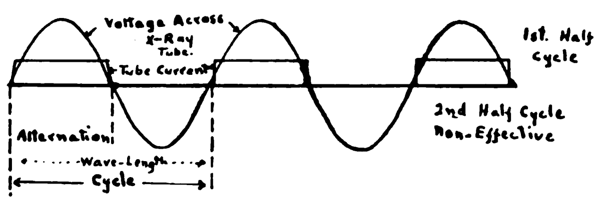


FIG. 83B. VOLTAGE AND CURRENT WAVE FORMS OF A SELF-RECTIFIED X-RAY CIRCUIT.

The filament (13) of the X-ray tube is heated by an intrinsic current furnished by the filament transformer secondary (14). This current is indirectly controlled by the primary circuit containing an ammeter (18) placed in series with the transformer primary (16) to determine the amount of current flow through the primary, which is regulated by the filament control (17).

In most X-ray machines, the control-board milliammeter makes an electrical connection at the center of the X-ray transformer secondary to record the current flow, and in some of the valve-tube rectified machines the potential meter (5) is replaced by a voltmeter calibrated to read the high tension potential in kilovolts directly.

It must be clearly understood that self-rectification is only feasible when a diagnostic type of X-ray tube furnished with coolers is employed in the apparatus. As for Coolidge air-cooled *universal* therapy tubes, in which the target becomes heated to the temperature of electron emission and hence the current through the tube can pass in both directions, self-rectification becomes an utter risk as to the possible cause of damage to the filament, or, otherwise to cut short the tube life. A *universal* therapy tube, therefore, should never be put into use if it is expected to rectify its own current. Accordingly, a full-wave rectified circuit is the one most satisfactory for this type of tube.

2. Mechanical Full-Wave Rectification.—Up till recent years mechanical rectifiers have had extensive application due to their robust construction, low cost of maintenance, and their applicability to various clinical demands. The invention of the device is attributed to C. S. Snook, who first developed, in 1908, the transformer pole-changing device quite akin to present cross-arm type rectifier, which is essentially a rotary switch whose speed of rotation is synchronized with the frequency of the alternating current exciting the X-ray tube. That is, the cross-arm, or the rotary switch, is rotated by a synchronous motor at a speed equal to half the supply frequency in cycles per second. For a 60-cycle current, then, the rectifier switch rotates 30 times per second, and for 50-cycle current, it rotates 25 times per second .

The purpose of the rotating switch is to rectify the high tension alternating current before it enters the X-ray tube. This is accomplished by arranging two pairs of contactor arms coupled to the shaft of the synchronous motor, which is insulated from the contactors, in such a manner that the mid-point of each arm is positioned at 90 degrees from the corresponding point of the successive arm, and each pair, functioning together, closes the circuit during each alternation of the current in the secondary of the X-ray transformer by contacting the corresponding stationay brushes attached to the aerial circuit. The interval of time elapsing during the contact between the cross-arms and the collectors determines the portion of each alternation used. This value is also dependent upon the peripheral length of each arm in respect to the collector brush. With earlier machines this interval has been very short with the consequence that only a small upper portion of the wave peak is utilized through the X-ray tube. This is, however, of advantage in that the X-rays thus produced are more penetrating, whereas were the lower portions of the wave also utilized the condition would unavoidably contribute to the unnecessary heating of the anode without improving the quality of the X-ray emission.

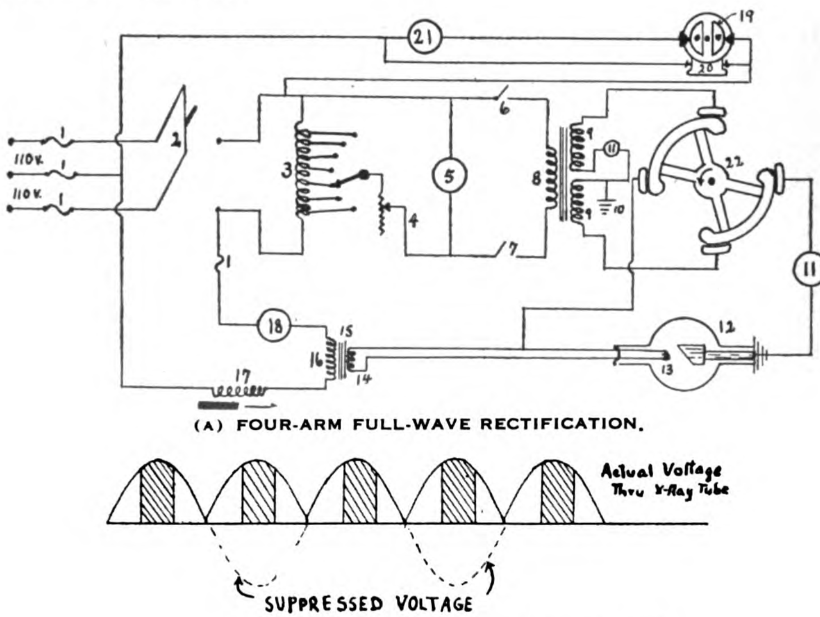
To rectify the alternating current, the rotary switch (either four-arm type, or disc type) is rotated by a synchronous motor, which is operated on the same current supply as the X-ray tube. Since the shaft of this motor is continuous with the axle of the rectifier disc, or the cross-arm, each time the armature makes a complete rotation the cross-arm also makes a complete rotation.

During each revolution of the rectifying unit, the current through the system alternates four times, each alternation passing consecutively through each pair of the cross-arms. As the current changes polarity, or proceeds one alternation, simultaneously each pair of the cross-arms rotates 90 degrees, and becomes co-incident with the next set of collector brushes from the X-ray aerial. This reverses the connection to the tube, and at the same time, shifting the direction of the flow of the inverse current during this alternation to the same direction as the preceding alternation through the X-ray tube. Consequently, the process permits both halves of the cycle to flow in the same direction, thus rectifying the current that excites the X-ray tube.

At present, both the disc type and the cross-arm type of mechanical rectifying units are in general use in clinics or laboratories. Most of

these units are installed before the valve-rectification gained prominence in recent years. The mechanical rectifier has, however, its advantages over the valve rectification in that the former does not have parts that easily get out of order, or otherwise fail to function unexpectedly, as might be the case with valve tubes which are liable to burn out any time while in use. Furthermore, mechanical rectifiers produce more of the penetrating X-rays, since only the peaks of the current waves are utilized. This eliminates the use of filters for certain roentgenographic technics, and increases the permissibility of greater number of radiographs to be taken within the limits of the skin erythema effects, since there will be less of the longer waves which are easily absorbed by the skin and do not contribute to producing the radiograph. On the other hand, valve-tube rectification has many distinct advantages over mechanical rectification, and we shall further take this up in detail in our discussion on valve-rectification.

The circuit diagram of a mechanically-rectified apparatus is given in Fig. 84 (a), and the curve of the useful portion of the pulsating voltage through the X-ray tube is shown in (b). The rectifying unit chosen is the Cross-Arm (22).



(A) FOUR-ARM FULL-WAVE RECTIFICATION.

(B) VOLTAGE PEAKS ACROSS THE X-RAY TUBE.
FIGURE 84.

In the figure, a polarity commutator (19) is attached at one end of the shaft of a synchronous motor (20), and furnishes the current that actuates the polarity indicator (21). The commutator consists of a disc formed by two bronze plates having half-moon shapes and insulated one from the other by mica or air-gap of about 1 mm thickness. The purpose in having the two separate half discs co-axially mounted together is to

suppress, by this arrangement, each half of the alternating current cycle and to allow a unidirectional pulsating current through the polarity indicator (21), which indicates the would-be direction of the current through the X-ray tube when energized.

As the motor and the commutator together make a complete rotation, the circuit current alternates four times, every other alternation passing through the polarity commutator. These alternations, in turn, are "caught" and registered by the polarity indicator. The explanation of this semi-rectification associated with the rotation of the synchronous motor is more fully offered by a study of the section on polarity commutator.

(a) *The Autotransformer.*—Built on much of the same principle as a potentiometer, an autotransformer offers an ideal means of control over the high tension voltage of the X-ray circuit. The device consists of a single winding around a soft iron core. This winding takes the place of both the primary and the secondary of an ordinary transformer. If the extreme ends of the coil are connected to the supply line, this portion will represent the primary winding, and a connection made from one of the leads at either extreme ends to a tapping taken from any given point on the coil will constitute the secondary winding. Therefore, taking suitable tappings from the different sections at intervals of definite number of turns of wire on the transformer winding affords the transformer to vary its output with a relatively comprehensive selection of voltages with each shift from one tapping to the other. These tappings may terminate at suitable metallic buttons over which the transformer control knob conveniently slides during a shift from one voltage to the other.

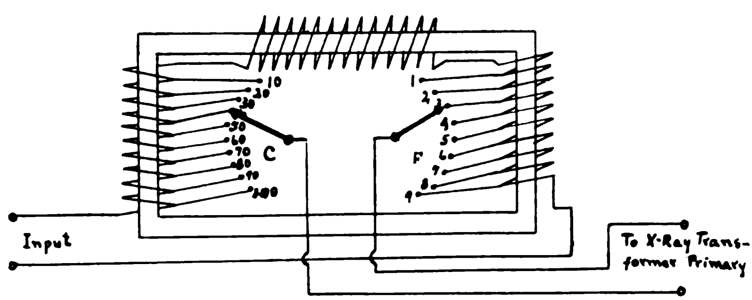


FIG. 85. THE AUTOTRANSFORMER.

The device shown in Fig. 85 has two sets of dial studs, and its winding consists of the two corresponding sections, one of which, marked by F, has smaller number of turns and contains practically as many tapped-in portions as the other section C. The division of the winding into two sets of tappings affords the advantage of two different selections of voltages — the selection from one dial, C, varying the potential, for instance, in steps of 10 volts, and a finer control of voltage, say, in 1-volt steps being secured from the other dial stud in F. An arrangement such as this offers a uniform potential control from 10 volts to 225 volts, the supply voltage, in steps of one volt. Since such a fine voltage selection will necessitate the building of a bulk unit, most X-ray machines are

equipped with two sets of voltage control dials, in which the voltage is varied in steps of 2 or 3 volts, thus affording a more compact construction of the autotransformer.

The input energy in each set of winding is uniformly distributed throughout its entire range. Hence, the voltages between any two consecutive taps of a given set on the winding are equal, since any two of the inter-tap spaces contain the same number of turns. For instance, in section F, the voltage between the buttons 6 and 7 is same as that, say, between the buttons 2 and 3. Similarly, any two sections in C have equal potential differences. By adjusting these controls to suitable buttons, a uniform selection of voltages up to the supply voltage can be conveniently made.

The principal objection to this arrangement is that the autotransformer control can not be varied while the X-ray tube is excited, since in shifting the control from one button to the other the X-ray circuit will be opened, subjecting the X-ray tube current to sudden fluctuations which will increase the burden on the tube by causing impulsive agitations in the applied voltage. This difficulty, however, can be overcome to a certain extent by inserting unipolar resistances between the studs from each tap, or by furnishing the contacting brush of the control knob with split legs, held together by a spring, so that when one leg is about to make a contact with the next stud, the other leg just detaches itself from the preceding stud by the action of the spring.

Unlike the rheostat arrangement of a potentiometer, the autotransformer controls the voltage output by producing in its winding a counter-electromotive force which offers resistance to the variations of voltage to values other than set forth on the control dial. Due to this effect of self-induction, practically no power is dissipated in the form of heat (I^2R) as would be the case if a rheostat is used to accomplish this purpose. Thus, the autotransformer offers a distinct advantage over the rheostatically-controlled circuits which involve the loss of power with a consequent evolution of heat undesirable in X-ray circuits.

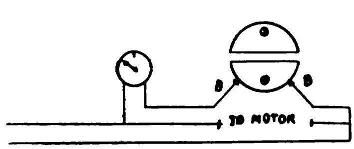


FIG. 86A. FIRST ALTERNATION CAUGHT BY POLARITY COMMUTATOR.

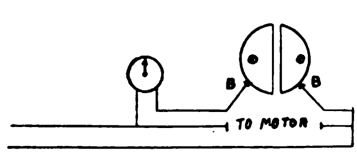


FIG. 86B. SECOND ALTERNATION MISSED BY POLARITY COMMUTATOR.

(*b*) *The Polarity Commutator.*—All mechanically rectified X-ray machines are equipped with a polarity indicator which determines the direction of the current flow through the X-ray tube. The device is essentially a small voltmeter with its zero point at the center of the meter scale so that the needle may respond to either polarity of the current passing through the instrument, and thus, indicating, before completing the X-ray circuit, whether or not the correct polarity of the current is realized. On either side of the zero mark, the instrument may be marked with *"correct"* and *"incorrect"*, corresponding to the respective directions of the current across the tube.

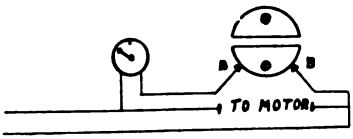


FIG. 86C. THIRD ALTERNATION CAUGHT BY POLARITY COMMUTATOR.

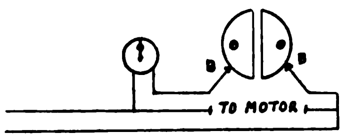


FIG. 86D. FOURTH ALTERNATION MISSED BY POLARITY COMMUTATOR.

The polarity indicator is electrically connected to a small rectifier switch, known as the polarity commutator, constituted by two half-circle metallic plates, each insulated from the other by a thin sheet of mica, or by an air-gap. This insulation serves to open the circuit to the polarity indicator during every other alternation of the current, thus suppressing all those every other half-waves that have similar polarities. The commutator, being mounted on the shaft of the synchronous motor, rotates with the same speed as the motor.

In operation, each time the commutator closes the circuit to the polarity indicator, current half-waves of similar polarities pass through it. This process permits through the indicator a unidirectional current flow, whatever the direction of the flow may be. In case the instrument indicates *"incorrect"*, the main switch is momentarily interrupted and then made, or, this is repeated if necessary a few times until the correct polarity is obtained.

The diagrams in Fig. 86 illustrate the *"caught"* and *"missed"* alternations by the polarity commutator during its one complete rotation, in which time the current through it alternates four times.

It will be noted in this illustration that since the contact brushes B are mounted at right angles to each other and to the axis of the motor shaft, they will open and close the circuit twice in every rotation of the commutator. The current to the indicator will then be interrupted once every cycle. The arrangement thus permits the flow of every other half-cycle through the instrument, and in a sense, the current, before passing through it, is rectified.

3. Cuprous Oxide Plate Rectification.—Reference has already been made on a previous occasion (See: Sect. 5, Part II, Chapter X) as regards the practical application of Cuprous Oxide rectifier to an X-ray circuit. In this connection it was stated that a rectifier of this type consists of a number of copper plates each coated on one side with Cuprous Oxide and placed closely together so that the coated surface of one plate is next to the untreated surface of the other to make a single unit. One or more of these units may be arranged either in the primary or in the secondary circuit of an X-ray transformer to produce a half-wave or a full-wave rectification, depending on the number of these units and on the manner of their arrangement. A circuit employing a set of four such units and producing a full-wave rectification is shown in Fig. 73. It must be well kept in mind, however, that if the rectifier units are inserted in the transformer primary no condenser in conjunction should be employed, as the latter will tend to smooth out the pulsations, militating against the voltage-multiplying properties of the transformer.

A plate rectifier unit for high-tension X-ray generator was made commercially available several years ago through Westinghouse Brake and Saxby Signal Company. The device is oil-immersed, and one type is designed to rectify a current of 30 M.A. at a tension of 200 Kv.P. By adequate design of the X-ray transformer the impedance and capacitance effects of the plates are overcome. Consequently, no appreciable distortion in the wave-forms of either the current or the voltage is incurred.

4. Valve-Tube Rectification.—The earliest type of valve-tube of most improved design and construction comprised a glass vessel enclosing a cold cathode in the form of a small disk and a spiral anode, shown in Fig. 87. The tube operated with a small amount of residual gas, which when diminished due to its adsorption on the glass envelope, was replenished by applying a high potential to the softening device (mica or carbon regenerator) provided in an auxiliary side tube, as at G in Fig. 87.

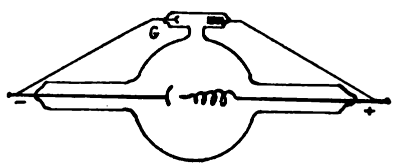


FIG. 87. VALVE-TUBE WITH SOFTENING DEVICE.

The rectifying action of this tube was obtained in view of the large surface area of the cathode, which permitted the passage of current more readily to the spiral anode when the latter had a positive polarity. The anode, however, passed a small amount of current in the reverse direction (toward the cathode) during the interval of the cycle when the cathode was positive. Obviously, then, such a tube did not provide a satisfactory means of suppressing the inverse current flow. Thus, with the advent of high vacuum hot-cathode tube, the gas-filled valve proved to be an inefficient component of X-ray apparatus, and soon was dispensed with.

Subsequent to Dr. W. D. Coolidge's announcement, in 1913, of a "new and powerful X-ray tube with pure electron discharge," the principle of hot-cathode discharge in vacuum was destined to become applicable to valve-tube rectifiers. Practically all of the present-day valve-tubes embody this principle because of its primarily affording a method which combines stability of operation with efficient valve rectification characteristics.

It will not be difficult to understand why a thermionic rectifying valve receives a marked preference if one considers that this type of rectifier presents qualifications unsurpassed by any other type of rectifying unit. For instance, the thermionic valve embodies noiseless operation, reliable performance, and owing to the absence of moving or rotating parts, mechanical vibrations are completely eliminated from the apparatus. Because of the practically complete suppression of high-voltage surges, and because of the perfect insulation of the cables (taking the place of overhead aerials) there is no spark or corona generated, and consequently, possible production of radio interferenrces, Nitrous Oxide, or Ozone, is eliminated. Furthermore, since there is practically no limit to the milliamperage that can be drawn across the tube, X-ray output of any quantity limited only by the load capacity of the X-ray tube can be realized by the use of a thermionic valve. Majority of the modern X-ray apparatus of either diagnostic or therapeutic type are provided with valve-tubes as standard equipment.

The thermionic valve comprises a highly evacuated envelope containing a filament cathode and an electron-receiving concave anode. The latter also may be in the form of a cylinder, which, then, completely encloses the cathode structure. When the filament is heated (to about 1000°C) it emits electrons in proportion to its temperature. The higher this temperature the more electrons are emitted. The application of a potential difference between the two electrodes is to impress a definite average velocity of drift on these electrons in the direction of the potential gradient. The incitation of this drift is dependent on the polarity of the filament, and that its magnitude is a direct function of the tube potential.

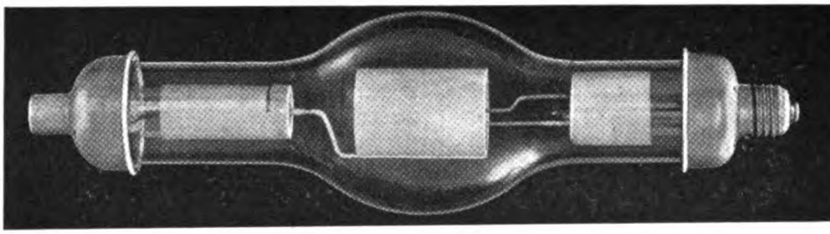
With an alternating current the incandescent cathode filament permits the escape of the electrons only during that alternation of the current when the filament polarity is negative with respect to the anode. As the filament becomes positive during the time interval of the next alternation, no electrons are emitted, and consequently, the current ceases to flow across the tube—hence the function of the tube as a valve. Since the anode temperature is sustained below that required for the emission of electrons, the electron flow can not reverse its direction. Thus, the device will permit the passage of the electrons only from the cathode to the anode once every cycle. The current, then known as having been *"rectified"*, will have a half-cycle, unipolar, and unidirectional wave form.

In constructing a valve-tube the same care as for an X-ray tube is exercised since the former is subject to the same difficulties as are prevalent during the building and processing of an X-ray tube, viz., the problem of attaining the highest possible vacuum and sustaining it during the entire life of the tube; the adequate cooling of the anode heated by the impact of the electrons; the provision of a sufficiently heavy filament for supplying an atmosphere of electrons which is many times denser than that supplied by the X-ray tube filament, for a given exposure technic; and, finally, to operate the filament, as much as is practicable, below the saturation point of the tube current for all exposure technics so as to prevent the incitation of the valve to X-ray emission.

A valve-tube operated beyond its saturation point is subject to a rise in its anode temperature as a result of a high voltage drop across it, and X-rays are inevitably produced. The condition is indicative of a dissipation of excessive power in the tube. Unless the cause is corrected, the life of the tube will be impaired.

At present several types of valve tubes are commercially available. Of these, the most common is the Kenotron, shown in Fig. 88. It comprises a cathode having a spiral tungsten filament fixed coaxially with the cylindrical anode of sheet molybdenum surrounding the filament. This type of construction is adopted because the arrangement has proved, in practice, that the voltage drop is relatively very small (several kilovolts) compared with an "end-on" type of construction in which there is a tendency of a drop as high as 10,000 to 20,000 volts. The result of such a high drop in voltage across the valve during an exposure with a given radiographic technic is equivalent of a blank film,

insofar as the interpretable features of the radiograph is concerned. During roentgen therapy, such a high drop in voltage will materially reduce the r-output. Hence, the adoption of the cylindrical type anode



(PHOTO — COURTESY OF GENERAL ELECTRIC X-RAY CORP.)
FIG. 88. MODEL KR-4 COOLIDGE KENOTRON FOR 140 KV.P.

is to maintain, as much as possible, a low voltage drop across the tube, and thereby to contribute to therapeutic and radiographic results which are always accurate, and each can be duplicated, when desired.

Generally, a valve having a glass envelope should be provided with a large bulb to dissipate the heat, and the glass arms should be sufficiently long so that adequate surface clearances between the outside terminals of the electrodes are afforded.

The Kenotron Model KR-4, Fig. 88, is designed for oil-immersed operation. It is rated to operate, in a four-valve full-wave rectifier unit, at a maximum permissible load of 140 Kv.P. (inverse) and 30 M.A. (D.C. equivalent) continuously, and at 120 Kv.P. (inverse) and 1000 M.A. (D.C. equivalent) for short periods. With latter load the voltage drop is claimed to be approximately 250 volts, which quantity is negligibly small. The filament rating ranges from 12.00 to 16.00 volts and 11.8 to 14.0 amperes.

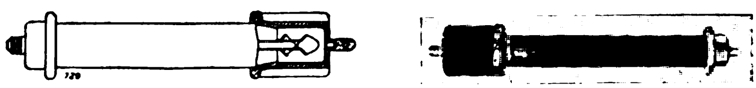
The KR-5 Kenotron, shown in Fig. 89, is designed to operate on 800,000 volt therapy installation. For operation in all types of rectification circuits except that of a constant potential, the KR-5 has a rating of 250 Kv.P. maximum inverse voltage and 500 M.A. maximum current for short-period loads, and 50 M.A.. for continuous operation. When connected in a constant potential circuit, the tube can withstand 215 Kv.P. maximum inverse kenotron voltage. Its filament rating is 7.0 to 9.5 volts and 11.5 to 14.0 amperes.

(PHOTO — COURTESY OF GENERAL ELECTRIC X-RAY CORP.)
FIG. 89. KR-5 COOLIDGE KENOTRON FOR USE IN 800,000-VOLT THERAPY CIRCUIT.

There are on the market a great many varieties of kenotrons manufactured by various manufacturers. Though differences exist in the design and construction of these tubes, in principle they all embody the same thermionic emission features of a Coolidge tube.

A new type of valve utilizes, in addition to its thermionic qualities, the application of the principles characteristic of Metalix X-ray tubes with metal discharge chambers. The development has emanated from Philips Metalix Laboratories in the year 1929. The tube is now commercially available in various load ratings.

In the Metalix valve, shown in Fig. 90, a chrome-iron cylinder which forms the actual anode, is welded vacuum-tight to the open end



(A) (B)

FIG. 90. METALIX VALVE-TUBE FOR 125 KV.P. AND 1000 M.A. (A) SEMI-SECTIONAL VIEW, AND (B) OUTSIDE VIEW OF THE TUBE.

of the glass sleeve which completely insulates the two electrodes from each other. Owing to the provision of a number of radiating fins (shown in (b) of Fig. 90) at the exterior portion of the anode which is open to the air, a high thermal conduction is assured. Centrally disposed is the generously designed tungsten filament which is held upright by a central metal pin projecting into the space enclosed by the cup-shaped anode.

It is claimed that because of the metal wall of the discharge chamber around the filament cathode being the anode itself, a reduction in the space charge effect (prevalent, to a certain extent, in all glass-envelope valves) to a minimum is effected, with the result that the voltage drop across the tube becomes surprisingly small. Consequently, a large electron emission is realized, and the tendency of over-heating the anode is practically nil. Due to such a unique design of the anode, X-rays that may be emitted as a result of insufficient filament current are largely prevented from emerging to the exterior of the tube.

We have already noted that the emission current across a thermionic tube is a function of the filament current (temperature) and of the applied voltage to the tube. The potential drop across the tube is due to space charge, and since in Metalix valves this effect is minimum, the voltage drop across it is negligibly small. Fig. 91 shows the characteristics of the Metalix valve compared with that of a glass valve for the same current value of the filament. The circuit diagram for obtaining the curves is given in Fig. 69a. For a fixed filament temperature at 8 amperes and 16.2 volts, it will be noted that the emission from the Metalix tube at saturation is almost twice as great with less than half the potential of that with a glass envelope valve. Similarly, with a filament current of 8.5 amperes at 18.0 volts, the Metalix tube attains its saturation point at a potential drop of 750 volts with an emission current of 1000 M.A. In the case of the glass-envelope valve, saturation is reached at about 2500 volts. The corresponding current at this voltage is only about 650 milliamperes.

Like the X-ray tube, the life of a thermionic valve tube is dependent on the tungsten filament. To realize the maximum life of a valve-tube, then, it must be sustained at a constant value of the potential and not

necessarily of the current. If, however, gassiness sets in due to an overload or leakage, the tube may undergo a sudden failure.

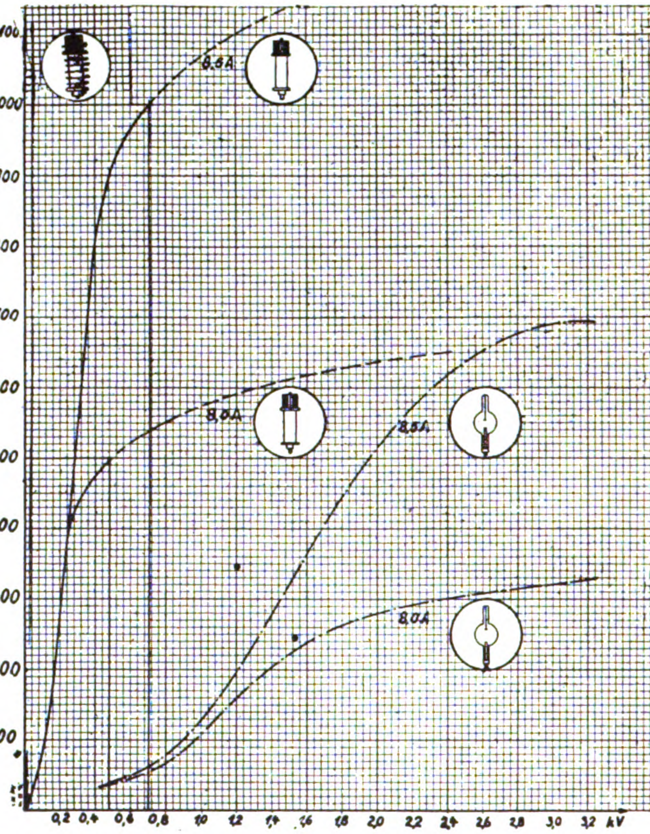


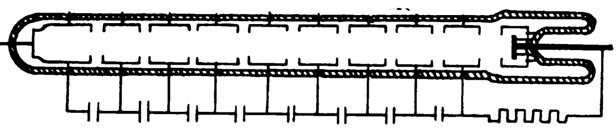
FIG. 91. COMPARATIVE CHARACTERISTICS FOR VARIOUS TYPES OF PHILIPS VALVE-TUBES.

Among other types of rectifying tubes of most recent origin, one of the most remarkable is the new Bouwers valve.* The tube, illustrated in Fig. 92, is a gas-filled multiple-discharge high tension rectifier. It consists of an oxide-coated cathode and a cylindrical cup-shaped anode sealed into the opposite ends of a tubular vessel, which contains eight metal intermediate discharge cells, Fig. 92b, dividing the space between the anode and the cathode into nine stages. The valve, after having been highly evacuated, is filled with a minute quantity of mercury vapor, which maintains a tube pressure equivalent to the vapor pressure of mercury at room temperature.

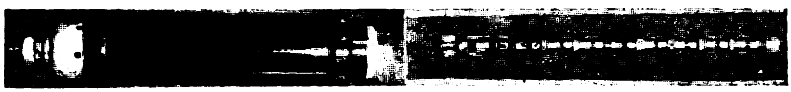
Concentrically to its long axis, the tube is surrounded by a number of cylindrical condensers arranged in series and each connected in parallel with individual stages, with the exception of the first stage at the cathode end which is shunted by a high resistance. The purpose of the

*Bouwers & Kuntke, Zts. Techn. Vol. 18, page 209, 1937.

condensers is to maintain an equal distribution of potential across successive stages. Another important function of these condensers is to prevent the possibility of a disturbance, in the starting of the discharge, influenced by the intense external electric field due to the portions of the consecutive discharge cells exposed to the air.



(A) SECTIONAL VIEW OF BOUWERS VALVE-TUBE.



(B) A COMMERCIAL FORM OF BOUWERS VALVE-TUBE.
FIG. 92. PHILIPS-METALIX GAS-FILLED RECTIFYING VALVE.

Valves of this design have been constructed to maintain an inverse constant potential of 225 kilovolts and are well adaptable for multistage X-ray generators rated at a million volts or over. The oxide-coated filament takes about 8 watts, and its temperature range is limited to a variation from 15 to 45 degrees centigrade. When a series of these valves are to be used, as in one to three million volt generators, Figs. 110 and 111, the method of heating the filament by high frequency (500,000 cycles) is preferred for various advantages of mechanical nature. Owing to the large emission properties of the *"dull emitter"* filament, the voltage drop across the tube when carrying a current of 1100 M.A. or over is only about 40 volts, as shown in Fig. 91.

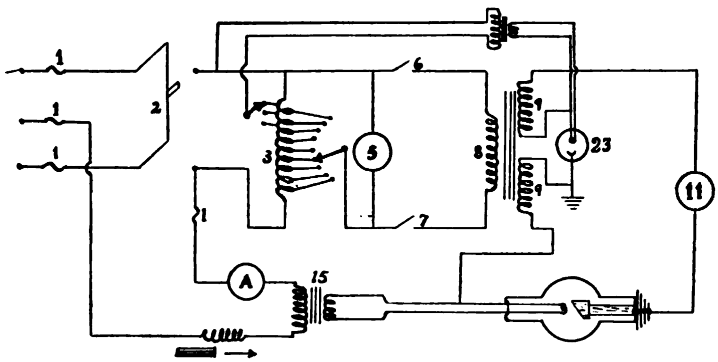
Low-tension valves for diagnostic apparatus are also available for various ratings, and, in practice, they have proved to be very useful in various types of generating circuits.

Gas-filled valve-tubes also have been produced by General Electric Company. One type used in diagnostic work contains an oxide-coated filament cathode surrounded by a cylindrical anode. The electrodes are enclosed by a glass envelope filled with an easily ionizable inert gas which provides a cumulative ionization in the tube. Owing to this latter effect the valve can pass a current as high as one ampere at an inverse tension of 120 Kv.P. The starting voltage is of the order of 40 to 80 volts, and at full load the tension drop across the tube is in the neighborhood of 20 volts—a characteristic well meeting the requirements imposed on thermionic discharge tubes.

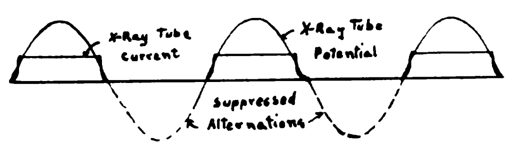
Rectification of the current to the X-ray tube may be achieved by connecting the valves either in the primary or in the secondary circuit of the X-ray transformer. The general trend, however, has adopted the latter arrangement because, aside from other advantages, the inverse voltage across the X-ray tube is relieved by the amount sustained across the valve tube, viz., half of the inverse voltage of the X-ray tube is suppressed by the valve, and the other half by the X-ray tube, in a single-valve rectification circuit.

In the accompanying sections, the use and the manner of employment of these valves in various types of circuits will be discussed as fully as space will permit.

(a) SINGLE VALVE RECTIFICATION.—(1) *Half-Wave Pulsating Circuit.*— The simplest valve rectified circuit involves a kenotron (23) connected in series with an X-ray tube, shown in (a) of Fig. 93. In this type of rectification, when the direction of the current is from the cathode to the anode of the valve, the tension drop is chiefly across the X-ray tube. But, when the current reverses its direction in the next alternation, the inverse potential from the transformer secondary is equally divided between the valve



(A) CIRCUIT DIAGRAM OF A SINGLE-VALVE UNIT.



(B) APPROXIMATE POTENTIAL AND CURRENT WAVE-FORMS.

FIG. 93. SINGLE-VALVE HALF-WAVE RECTIFICATION.

and the X-ray tube. Thus, the current passes across the X-ray tube during one-half of the cycle and is suppressed during next alternation. The actual current passing through the X-ray tube, therefore, has half-cycle, unipolar, and unidirectional wave-form, as given in (b) of Fig. 93. The process is known as half-wave rectification.

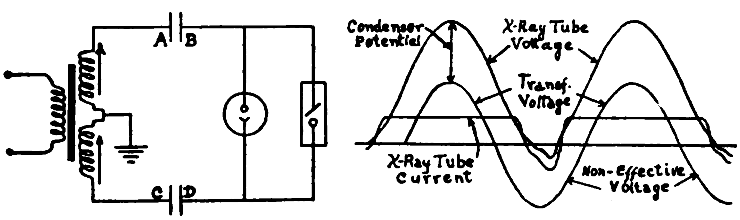
On a half-wave circuit, a radiograph made with an exposure time of, for instance, 1/20 second at 100 M.A. meter reading, the X-ray tube actually receives 200 milliamperes during every other alternation of the current. The fact lends itself to the production of a counter-electromotive current in the transformer secondary during that half-cycle of the current which is suppressed from the X-ray tube, and which current is supplemented to the next half-cycle of alternation allowed to pass through the X-ray tube. Thus, only one-half the number of impulses of the transformer secondary is delivered to the X-ray tube.

With a 60-cycle current at full-wave rectification, for instance, a 1/20th of a second exposure is equivalent to 6 impulses, 1/20th of 120 impulses,

and the X-ray tube will receive 6 impulses. In the case of a half-wave rectified circuit, however, the tube will receive, for the same exposure time, only 3 impulses but at twice the milliamperage indicated on the milliammeter. Though the exposure time and hence the milliampere-seconds are the same in both cases, a tube which is not designed to operate on half-wave will be subject to additional strains, with consequent shortening in its life.

(2) *Villard Circuit.*—One of the oldest yet now most popular X-ray circuit is the voltage-doubling one, first applied to practice by Villard.

The circuit, illustrated in Fig. 94a, comprises a valve-tube connected to the transformer terminals through two condensers arranged in series. In parallel with the valve-tube is an X-ray tube connected in opposition with the former. Since this arrangement supplies the X-ray tube with



(A) (B)

FIG. 94. DIAGRAM AND THE WAVE-FORM OF VILLARD CIRCUIT.

double the potential on the transformer, the valve must be capable to withstand the maximum tube tension without breakdown. In view of the latter position of the valve-tube, very high tension circuits employ two valves in series across the transformer, Fig. 99.

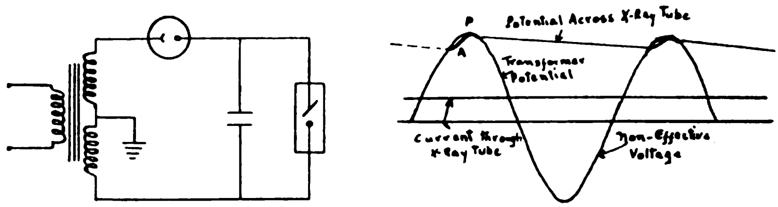
During the first half cycle when the current runs in the direction indicated by the arrows, the valve becomes energized. As in this alternation the electrons flow toward the plate A it becomes negatively charged while the plate C becomes positively charged. The concentration of the electrons at plate D, however, is influenced (increased) by the positive charge on C, charging D negatively with respect to C. Similarly, the plate B becomes charged positively in a magnitude equivalent to that on plate C. Thus, each condenser becomes loaded with approximately half the transformer voltage during the rising potential wave. The inverse potential across the X-ray tube is then equal to that across the valve, and is constituted by the voltage required to pass charging current across the condensers. The condensers continue to supply current to the X-ray tube during the falling of the voltage wave except during the short interval of inverse potential.

As the transformer polarity is reversed, the condenser voltages, supplemented by that of the transformer, are impressed on the X-ray tube with the rising potential wave. The current through the X-ray tube is maintained while its potential is falling back to zero. Thus, the voltage across the X-ray tube pulsates at twice the transformer potential and at the same frequency of the alternating current through the secondary

circuit. The approximate wave-forms of the respective voltages and the current are depicted in Fig. 94b.

The Villard circuit is extensively used in various roentgen therapy circuits because of its making it possible to use a transformer supplying only one-half the potential of the X-ray tube. For multiple-stage circuits, the Villard represents the nucleus of the combination.

(3) *Half-Wave Constant Potential Circuit.*—From the standpoint of roentgen-ray output, a supply of continuous current maintained at a uniform tension across an X-ray tube would appear most ideal. As no considerations of voltage or current wave-forms are presented, the radiation thus produced would consist of homogeneous wave-lengths of maximum penetration quality, practically exempt from long wave-lengths, which largely contribute to the heating of the X-ray tube. But, as pointed out



(A) (B)

FIG. 95. ILLUSTRATING (A) HALF-WAVE CONSTANT POTENTIAL CIRCUIT, AND (B) THE VOLTAGE WAVE-FORMS.

previously, it is not an easy matter to obtain a source of high-voltage direct-current due to difficulties lending themselves to the provision of adequate insulation of the equipment, and due to its cost, which is almost prohibitive. Nevertheless, an approximation to the electrical conditions maintained by the latter can be attained through the use of a simple X-ray generator containing one or more condensers in its secondary circuit.

A simple constant potential circuit employing only one-half of the transformer voltage wave is given in Fig. 95a. During the first alternation of the current which passes through the X-ray tube, the condenser becomes fully charged at the crest of the transformer potential wave. But, as this potential starts to fall, a difference of potential builds up across the valve tube, and the reduction dV in condenser potential which sustains the X-ray tube at a constant potential is given by the relation

$$dV = -\frac{i.dt}{C} \tag{103}$$

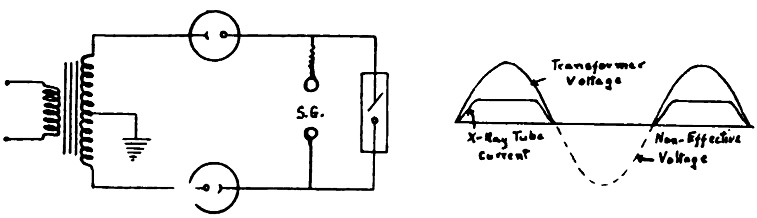
in which, i is the X-ray tube current maintained by the condenser having a capacitance C given in farads, and dt is a fraction of condenser discharge time in seconds.

The voltage across the valve reaches a maximum value as the transformer potential rises to its peak in the reverse direction. This gives rise to a slight fall of condenser potential which continues to fall until the transformer potential again reverses its direction and attains a value A, Fig. 95b, from which point on the condenser starts to build up to

the full transformer voltage, as at P. Thus the arrangement permits an uninterrupted current to flow across the X-ray tube impressed with a potential varying slightly in value amounting to about 10% of the transformer voltage maximum.

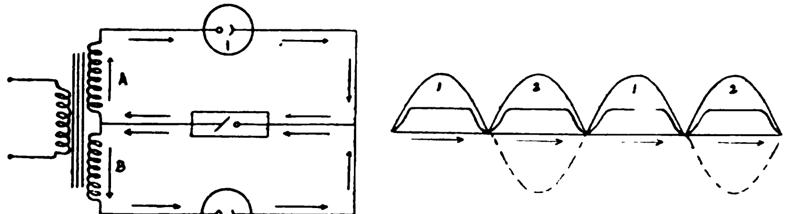
(b) Two Valve Rectification.—(1) *Half-Wave Circuit.*—In the circuit illustrated in Fig. 96, the rectification of the tube current is assisted by two valves, each connected to either terminal of the transformer and in series relation with the X-ray tube.

This type of arrangement is particularly adaptable to an equipment having a transformer sustained at a high inverse voltage. The X-ray tube receives only one-half of the transformer voltage wave, while the other half (inverse voltage) is suppressed jointly by the two valves and the X-ray tube itself. By connecting capacitances across two or more valves arranged in series with the terminals of the transformer secondary, the circuit may be made applicable to half-wave therapy apparatus for voltages as high as 500 Kv.P. But, the latter circuit, having met with limitations imposed by the valves connected nearest the transformer, has not found much favor particularly in view of other more recent circuits of greater adaptability to the field under consideration.



(A) (B)
FIG. 96. TWO-VALVE HALF-WAVE CIRCUIT.

(2) *Full-Wave Pulsating Circuit.*—In this arrangement, the cathodes are connected to one terminal of the transformer secondary, while their anodes are electrically joined through a common conductor. A pulsating full-wave current can be delivered to the X-ray tube by connecting its anode to the center of the transformer, and its cathode to the conductor intermediate to the anode terminals of the valves, as shown in Fig. 97.



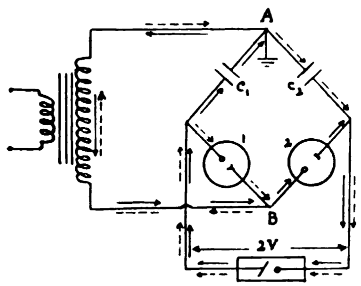
(A) (B)
FIG. 97. TWO-VALVE FULL-WAVE RECTIFICATION.

If the direction of the current through the transformer secondary is depicted by the arrow denoted by A, the valve 1 will become conducting,

and the first half-cycle will pass through the X-ray tube. When the current reverses its direction, (as at B) during next alternation, the valve 2 will conduct current to the X-ray tube. The symmetrical arrangement of the valves will thus permit the passage of both alternations of the complete cycle through the X-ray tube, which is excited at only one-half the entire transformer potential. Each valve tube, however, when not conducting, sustains the full transformer voltage.

It will be evident then that to energize the X-ray tube at various high potential values the transformer secondary must be maintained at correspondingly high potentials. For this and other obvious reasons the system, though convenient for low voltage ranges, is not adopted for commercial application. It finds, however, some use in experimental work.

(3) *Constant Potential Voltage-Doubling Circuit* (*Greinacher*).—A constant potential circuit which has found favorably large commercial application both in medicine and in industry is the one suggested by Greinacher. Two valve-tubes connected in series with each other and with two condensers of fairly large size form a bridge arrangement with respect to the transformer secondary and to the X-ray tube, shown in Fig. 98a.



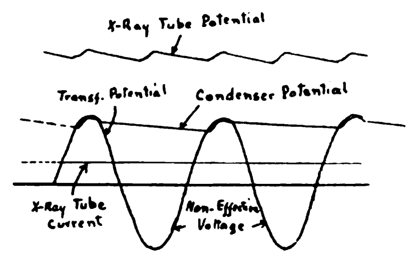


FIG. 98. (A) GREINACHER CIRCUIT. AND (B) WAVE-FORMS OF VOLTAGES AND CURRENT.

One terminal of the transformer connected at A between the two condensers is grounded that the tension at B alternates between a maximum of one polarity to that of another polarity. The X-ray tube, having been connected across the outer plates of the condensers, is energized at twice the transformer potential constituted by the combined potentials of both the transformer and the respective condenser.

In operation, if the direction of the first half-cycle of the current through the transformer secondary is, for instance, from A to B, the valve-tube 2 becomes conducting, and charges the condenser C_2 to full transformer voltage. The X-ray tube then receives the whole transformer potential plus that from condenser C_1 charged from a previous half-cycle—a total of approximately double the voltage of the transformer. As the current reverses its direction (indicated by broken arrows), the transformer voltage supplemented by that of C_2 drives the current through the X-ray tube, then through the valve 1, back to the positive terminal B of the transformer. Thus, a continuous current is maintained through the X-ray tube while the transformer current alternates twice.

While the valve-tube 1 is conducting, the condenser C_1 becomes fully charged to the same potential of the transformer. Hence, the flow through the X-ray tube continues drawing current alternately from each of the condensers. The wave-forms are depicted in Fig. 98b. The circuit renders itself valuable from the standpoint of economy in adequate insulation of the transformer secondaries from ground.

It will be shown presently that a series of Greinacher circuits can be cascaded to produce almost any voltage limited only by transformer insulation problems.

(4) *Voltage-Doubling Circuit* (*Garretson*).—The Garretson circuit comprises two valve-tubes connected through two condensers in series with the transformer winding, whose center in conjunction with the common point of connection of the two valves is grounded, as shown in Fig. 99.

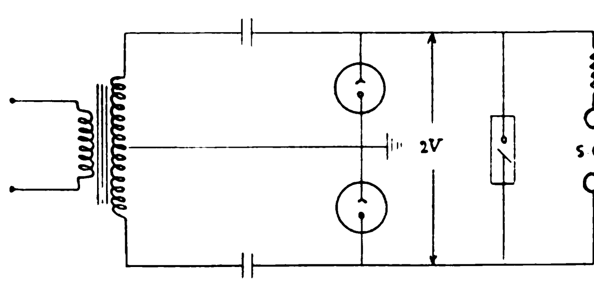


FIG. 99. VOLTAGE-DOUBLING CIRCUIT.

The wave-form of the potential through the X-ray tube, and the operating characteristics of the generator are similar respectively to those depicted by Villard circuit, Fig. 94. Since with this circuit only one-half of the potential difference sustained at the X-ray tube is supplied by the transformer (the other half being furnished by the condensers), the insulation problems thus become relatively simple. The circuit is extensively used, therefore, for both therapy, and in industrial diagnostic work.

(5) *Voltage-Tripling Circuit* (*Witka*).—Although the commercial application of this circuit is rarely met with, nevertheless, we shall discuss it with the view of giving the principal features of its importance as a simple voltage *triplicator* as well as its efficiency of roentgen output.

Two circuits, each consisting of a valve and a condenser, are connected in parallel with the secondary of an X-ray transformer, as shown in

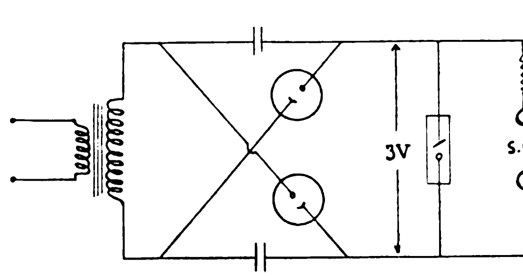


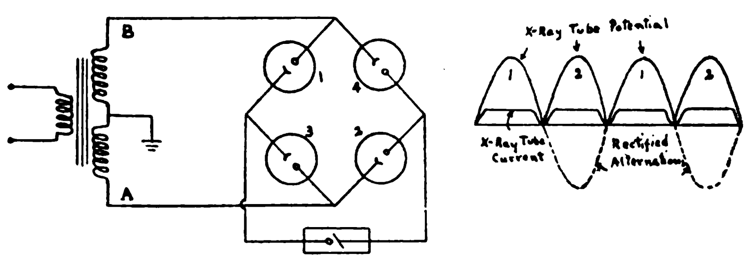
FIG. 100. VOLTAGE-TRIPLING CIRCUIT.

Fig. 100. During the first alternation of the current (whose direction is marked by the arrow), each condenser is charged to approximately full voltage of the transformer, and for a brief portion of this period no current passes through the X-ray tube.

As the current alternates, the next half-cycle of the transformer potential becomes supplemented by the condensers thrown in series with the X-ray tube and the transformer. Since the valves are non-conducting during this interval of the current cycle, the X-ray tube receives the combined potentials of the two valves and the transformer.

Recalling that each condenser was charged, during the first half-cycle of the current, to the full transformer potential, the total voltage across the X-ray tube during the second half of the cycle, then, would be three times the potential on the transformer less the voltage drop in the valves and that across the condensers. The voltage value through the X-ray tube then alternates from V, the transformer voltage, to $3V$ approximately. Hence, one of the valves should be insulated from earth for V, while the other for $3V$, which values may be halved if the transformer secondary is grounded at its center. The wave-form of the circuit is somewhat similar to that depicted by Villard circuit, Fig. 94b, except that the amplitude of the tube potential wave is approximately three times that of the transformer.

(c) FOUR VALVE RECTIFICATION.—(1) *Full-Wave Gratz Circuit.*—One of the most popular circuits for obtaining full-wave rectification at full transformer potential is that employing four valve-tubes, shown in Fig. 101. The circuit, first suggested by Gratz, has bridge arrangement, in which two valves function during one half of the cycle and the other two during the other half.



(A) (B)

FIG. 101. FOUR-VALVE FULL-WAVE RECTIFICATION.

When the current in the transformer flows from A to B the valves 1 and 2 become conducting, and the current passes through the valve 1, the X-ray tube, the valve 2, and back to the transformer, as at A, while valves 3 and 4 are non-conducting. The first half-cycle, marked by 1 in Fig. 101b, is thus permitted to pass through the X-ray tube. As the current reverses its direction, it flows from B to A in the transformer, and passes through the valve 3, the X-ray tube, the valve 4, and back to B, allowing the second half of the cycle, marked by 2 in Fig. 101b, through the X-ray tube.

While all the four valves take part in delivering current to the X-ray tube during one complete cycle of the current, it is obvious that only two are energized at a time. The operation thus continues supplying current to the X-ray tube alternately through each respective pair of the valve tubes during the entire duration of the X-ray load.

The Gratz circuit can be arranged to serve dual purpose by providing a double-throw switch between the valve tubes on one side of the bridge and the conductor lead from the center point of the transformer. When this switch is in "off" position the circuit functions as Gratz connection, and, when it is in "on" position it connects the anode of the X-ray tube to the center of the transformer, and disconnects the currents to the filaments of the valves connected on the same side. A full-wave current at half the normal voltage of the transformer can be secured with this arrangement. Since two of the valves are non-conducting, the rectification characteristic of the circuit becomes similar to that shown in Fig. 97 —a full-wave current of high capacity at half the voltage of the transformer secondary can be delivered to the X-ray tube. Such a circuit is of special advantage when a high milliamperage technic at relatively low voltage is desired, as in X-ray spectrography.

(2) *Mutscheller Circuit.*—A voltage-multiplying circuit employing three 75-Kv.P. X-ray transformers in a combination of Greinacher and a half-wave constant potential arrangements for obtaining 300 kilovolts constant potential has been described by Mutscheller in the American Journal of Roentgenology, Vol. 17, 1927. The circuit connection is given in Fig. 102, which shows a Greinacher circuit A-A centrally arranged between two

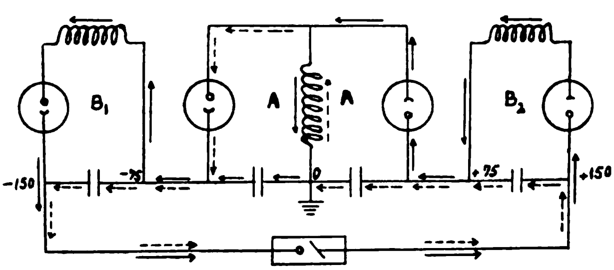


FIG. 102. 300-KV CONSTANT POTENTIAL MUTSCHELLER CIRCUIT.

elementary constant potential circuits B_1-B_2 energized independently by two separate 75 Kv.P. transformers. Also, a similar transformer is employed in the central circuit.

Referring to the operative characteristics of each type of the circuits presented in the figure, it will be recalled that the center connection is a constant voltage-doubling circuit, and those on either side are half-wave constant potential arrangements. Since each of the three stages is energized by 75 Kv.P., by proper arrangement of the valves and the condensers, a positive potential of 75 KV (with reference to the negative pole of the transformer) at the cathode end of the valve in B_2 and a negative potential of equal magnitude at the anode terminal of the valve in B_1 may be normally obtained. The center circuit A-A has one end of its transformer secondary grounded so that a positive potential of 75 kilovolts

against earth is developed at the right-hand side of the branched circuit and a negative potential of 75 kilovolts to earth at the left. Accordingly, the portion of the entire circuit to the left from the grounded point (which is at zero potential) develops a total of – 150 KV, whereas to the right from this point a potential of +150 KV is obtained. Thus, the difference of potential across the X-ray tube is sustained between —150 KV and +150 KV., viz., a total tension of 300 KV is maintained at the X-ray tube. The direction of the current flow is denoted by the arrows.

Since the charging frequency of each condenser in the circuit A-A is double that of the condenser at either side, the capacity of the former need be only one-half that of the latter condenser, whose corresponding valve must be insulated from ground to twice the transformer potential.

(3) *Bouwers' Voltage-Multiplying Circuit.*—A. Bouwers* has developed a high voltage generator circuit employing four valves and four condensers, shown in Fig. 103. The system enjoys the advantage of the principle of a simple Villard circuit whose voltage is extended by successive additions of valve and condenser.

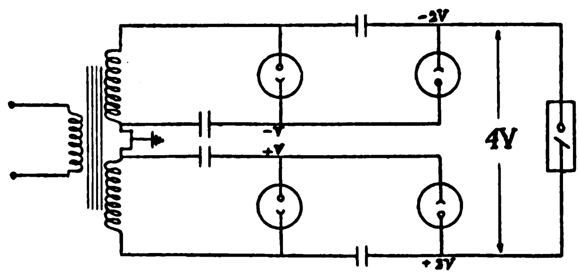


FIG. 103. BOUWERS' HIGH-VOLTAGE GENERATING CIRCUIT.

The arrangement represents the effect of two Villard circuits connected in series at each half of the transformer secondary that the potential at each section on either side of the earthed center point of the winding is built up to four times the potential of the corresponding section of the transformer. But, since each section furnishes only one-half of the overall transformer tension ($\frac{1}{2}V$), the combination of valves and condensers on the corresponding side will develop a potential of $2V$ against earth ($4 \times \frac{1}{2}V = 2V$). This may be a negative potential ($-2V$), as indicated at the cathode lead of the X-ray tube, or a positive potential ($+2V$), indicated at the anode side of the X-ray tube, either potential compared with respect to earth. The potential sustained at the X-ray tube, then, is the difference of $—2V$ and $+V$, or simply $4V$.

(4) *400,000-Volt Constant Potential Circuit.*—One of the most recent types of high-voltage roentgen-ray equipment for practical use is the one described by Gross‡, of General Electric X-ray Corporation. The

*Brit. J. of Radiology, Vol. VII, Page 21, 1934.

‡M. J. Gross, The Amer. J. of Roentg. & Radium Therapy, Vol. 36, No. 4, Oct., 1936.

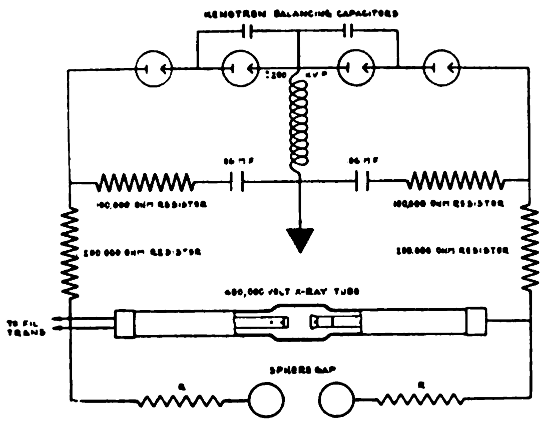


FIG. 104. 400,000-VOLT AND 5-M.A. CONSTANT POTENTIAL CIRCUIT EMPLOYING XPT-4 COOLIDGE TUBE.

energizing circuit, schematically represented in Fig. 104, is center-grounded so that spacings for only 200,000 volts to earth are required when operated with an XPT-4 Coolidge X-ray tube, as illustrated in the figure.

The essential characteristic of the equipment centers around the inclusion of sufficient electrical impedance in series on either side of the X-ray tube. The importance of this procedure can not be overemphasized, as otherwise the instantaneous current and voltage surges may be accompanied by instability in tube performance—the chief reason why earlier constant potential equipments of the type have failed to function properly. Experience has shown that a resistance of at least one ohm per volt of the X-ray tube potential must be included in that portion of the circuit which is in series relation with the tube.

It is further suggested that a means for gradually raising the high tension must be provided so as to avoid a sudden application of the full voltage to the X-ray tube upon switching on the high tension, viz., the tube voltage must be raised gradually to its full value. A still further suggestion of great importance as regards the circuit is the provision of a protective sphere-gap across the X-ray tube for discouraging the growth of over-voltage surges as well as for carrying out voltage measurements when desired. The [illegible] enable the calibration to be made on the equipment from time to time.

(d) SIX VALVE RECTIFICATION.—For nearly a decade, roentgen generators furnished with six valve-tubes have been used with satisfactory results, but the scheme has not become generalized for diagnostic apparatus in view of the cost of the equipment, difficulty in securing a multiphase high-frequency current source at any desired location where the apparatus is to be operated, and, above all, the advantages realized with this type of circuit seem to have no practical bearing on the radiographic quality.

The fact that this type of rectification scheme when applied to diagnostic apparatus produces more homogeneous X-ray radiation at tensions exceeding 50 Kv.P., and further permits a higher specific load to be applied to the X-ray tube whereby a simultaneous reduction in time of short-period exposures (less than .1 second) is realized, the advantages thus gained over a four-valve machine do not appear to justify the adoption of the six-valve apparatus in general diagnostic practice. For instance, in a six-valve generator the load on the focal spot may be increased 1.4 times that permissible with a circuit equipped with four

valves. But, with this increase of load the dimensions of the focal spot must be correspondingly increased, resulting in loss of definition due to a large focus area. As regards the radiographic improvement obtained by a reduction in exposure time, the alteration is only 10 per cent, which quantity does not produce any distinguishable effect on the radiograph. Hence, the difference of improvement obtained with a six-valve apparatus and that furnished with four valves is of no practical consequence.

It will be noted, however, that a three-phase star-connected supply may be applied to a six-valve circuit arranged so that each pair of valves will conduct current equivalent to a single-phase supply. The principle when adopted in a high-voltage therapy apparatus somewhat alters the question regarding its utility in that an approximation of constant potential (See: Fig. 107b) with a simultaneous increase in X-ray output (essential in therapeutics) can be conveniently realized without recourse to condensers and impedance coils.

(1) *Cascade Circuit With Villard Arrangement.*—By arranging together a series of Villard circuits, Bouwers* has developed cascade generators furnishing from 400 KV to 3000 KV constant potentials with current intensities of several milliamperes minimum. Cascade circuits of this type lend themselves to the provision of a number of valves and condensers energized by an alternating current source having a frequency preferably 200 cycles or over. The circuit arrangement of a six-valve generator producing six times the normal potential difference of the transformer is diagrammatically given in Fig. 105.

When current flows through the circuit the condenser C_1 becomes charged to the full voltage V of the transformer, while the potential difference at indivdual valves alternates between the values $2V$ and 0. Considering the sectional circuit included by condenser C_2, it will be found that the latter is charged to a potential $2V$. Similarly, C_3, C_4, C_5, and

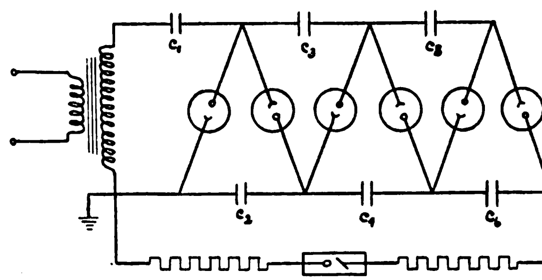


FIG. 105. CIRCUIT DIAGRAM OF A SIX-VALVE HIGH-VOLTAGE GENERATOR.

C_6 will each acquire a voltage $2V$. The total voltage available at the X-ray tube is half that on the condensers, or simply, the sum of the voltages on the condensers C_2, C_4, and C_6, a total of $6V$. If the transformer peak potential is 100 KV, the X-ray tube will receive 600 KV (minus the potential drop in the impedance).

It will be fully justified then to anticipate on the application of the principle already described to the construction of generators to produce poten-

*A. Bouwers & A. Kuntke, Zts. Techn. Phys., Page 209, Vol. XVIII, 1937.

tials (only limited by transformer output) as high as 5-million volts with some future advance in this direction.

(2) *Cascade Circuit With Greinacher Arrangement.*—Another method of special interest for generating high potentials is that due to a cascade arrangement of a number of Greinacher units. The circuit illustrated in

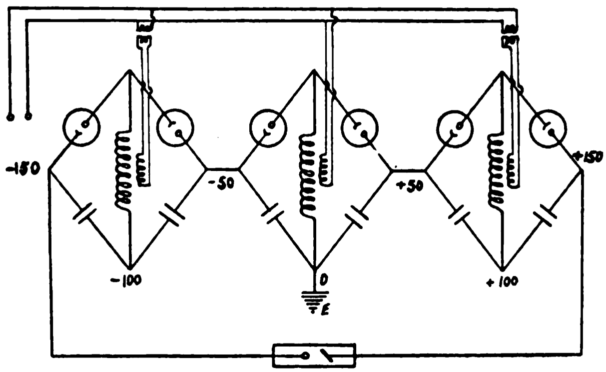


FIG. 106. 300-KV CASADE CIRCUIT USING THREE GREINACHER UNITS IN SERIES.

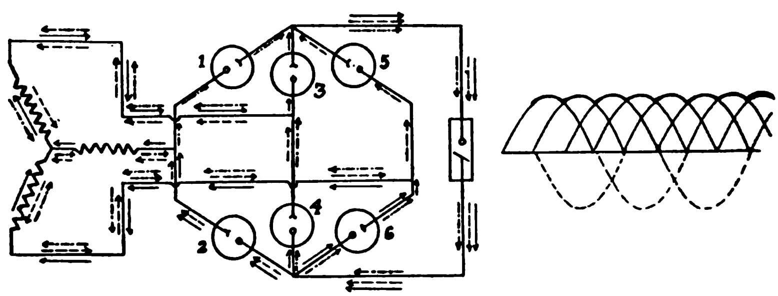
Fig. 106 comprises three of such units connected together in series and energized by three 50-Kv.P. X-ray transformers, producing an overall voltage of 300 KV available at the X-ray tube.

It will be noted that the primaries of the main transformers on either side are each energized by an insulating transformer, while that of the middle transformer is directly connected to the mains supply. The purpose for such an arrangement will be obvious by considering that the secondary winding of each side transformer is in series with that of the middle transformer. One end of the transformer secondary of the center unit being grounded it only requires to be insulated from the primary for 50 KV, whereas the secondaries of the side transformers being in series with that of the center transformer can each sustain 100 KV, and, therefore, must be insulated from ground for 100 KV. This latter position of the transformer necessitates its connection to the supply line through an insulating transformer.

As the potential difference that avails itself across each one of the six condensers is 50 KV its plates must be insulated from each other for that voltage. The individual capacities of the condensers being equal the maximum direct voltage furnished across the system is the sum of the condenser potentials in series, which amounts to a difference of potential of 300 KV—a positive potential of 150 KV against earth, and a negative potential of 150 KV to earth, which latter connection is made at the center of the main circuit.

In practice, each Greinacher unit, with the exception of its two valves, is immersed in a single oil-filled container, which is insulated from ground for the maximum potential sustained by its content. The extention of such series-connected units to a million-volt generator is discussed in Section (e) with illustrations given in Fig. 109.

(3) *Three-Phase Six-Valve Circuit.*—Enough has been said already in the introductory part of this section as regards the merits of the application of a three-phase alternating current to X-ray generators. It remains now to mention that if a three-phase supply source is available, and the radiographic technics called more frequently for high-speed exposures, that a sacrifice in tube life as a result of high tube-current together with the cost of equipment and maintenance are of no special concern, the adoption of the scheme appears to be the logical sequence. When such a plan is undertaken, a mechanical rectifier, employing a split-phase arrangement in which the X-ray transformer, the synchronous motor, and the filament-heating transformer, each receives one phase without being affected by voltage fluctuations in any of the other circuits, may prove more advantageous from the standpoint of economy. However, owing to the high operating efficiency and extreme flexibility afforded by a modern valve-tube through its carefully designed construction in a manner to insure the longest possible tube life its adoption in multi-phase circuit arrangement is of special interest. A three-phase circuit employing six valves and giving an approximation of constant potential with less than 1.2% ripple is illustrated in Fig. 107.



(A) (B)
FIG. 107. (A) SIX-VALVE CIRCUIT USING THREE-PHASE CURRENT, AND (B) WAVE-FORM OF THE VOLTAGE.

The X-ray tube is connected across the valves, which are arranged in pairs and in series relation to the tube. It receives one impulse per 60-electrical-time-degrees, or 360 impulses per second, each valve carrying one-third of this number. Since there is a phase difference of 60 degrees between each two consecutive impulses, if, for instance, the valve 1 passes current to the X-ray tube, the valves 4 and 6 return it to the corresponding coils of the transformers; and, if valve 3 is conducting current to the X-ray tube, the valves 2 and 6 return it to the respective phase windings, and so on.

As individual phase lines furnish equal potentials, V, for instance, the maximum tension sustained across the valves as well as the X-ray tube is the vector sum of all the individual phase voltages of the mains supply, i.e., a total of $\sqrt{3}\ V$. But, due to the capacity effect produced by the cables, X-ray and tlectrical protection shields, etc., the tendency of this to increase 16%, or to $2V$, with X-ray tube current at a minimum limiting value is well indicated.

To insure against overload, the radiologist frequently loads the X-ray tube at 65% to 80% the maximum permissible ratings, resulting in a sacrifice of the advantages gained through the use of a six-valve three-phase apparatus. Consequently, from the foregoing we arrive at a conclusion whereby the question of whether or not the adoption of the latter circuit to diagnostic equipment is superior to that furnished with four valves remains open subject to some further advance yet to be made in this direction.

(e) MULTI-STAGE CASCADE GENERATORS IN EXCESS OF 800 KV.—The important characteristics of simpler voltage-multiplying units in their adaptability to cascading have already been discussed. Therefore, the accompanying circuits are given only from the point of view of stressing upon the specific points of interest attaching to the circuit requirements of high voltage generators.

(1) *Eight-Valve Voltage-Multiplying Circuit.*—The diagram illustrated in Fig. 108 is an extension of the familiar Bouwers voltage-multiplying circuit shown in Fig. 103 to 8-valve arrangement. It will be recalled that each of the two divided sections of the X-ray transformer secondary includes an equal number of valves and capacitances, and that the combination of a valve and a capacitance is responsible, in a single stage, for doubling the difference of potential sustained at the portion of the trans-

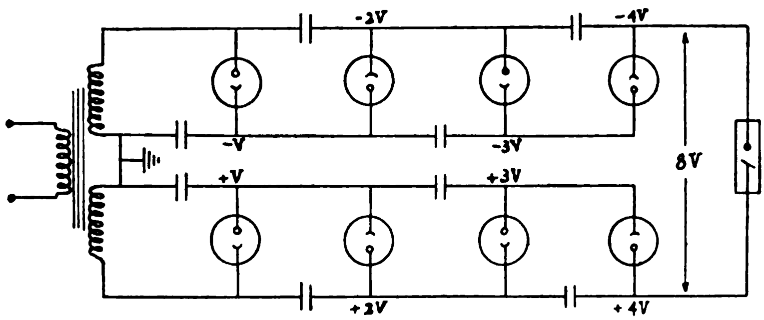


FIG. 108. 800-KV VOLTAGE-MULTIPLYING CIRCUIT DUE TO BOUWERS.

former across which these elementary units are connected. As mentioned previously, the connection consists of a number of Villard circuits placed in series on either side of the main transformer, whereby the terminal potential constituted by the combined potentials of the individual elemenary circuits is extended to a value limited by the number of these series circuits and by the transformer output voltage.

The secondary of the transformer having been grounded at its center it is only necessary to insulate this winding from the primary for half the maximum voltage, or $\frac{1}{2}V$, where V is the maximum potential output of the transformer. The first elementary circuit (consisting of a valve and a condenser) will then raise this voltage to twice its value, which is $\frac{1}{2}V \times 2 = V$. The next circuit will double this to $2V$, and the third to $3V$, and so on to the last stage, whose potential in the case under consideration is $4V$.

It should be kept well in mind that potential values assigned to the

terminals of the individual circuits are only relative, as will be seen in equation (104).

$$V = 2nV - \Delta V \tag{104}$$

in which, V is the maximum potential of the transformer secondary, n the number of elementary circuits or stages, and ΔV is the total potential drop due to valves, condensers, and ripplage. Therefore, this factor (ΔV) must be compensated for by the transformer output, viz., the transformer in the above consideration must put out a voltage of approximately ($V + V/n$). ΔV may, however, be decreased to a certain extent by slightly raising the frequency of the transformer input.

(2) *Seven-Unit One-Million Volt Cascade Generator.*—The principle of the Greinacher circuit which is employed to produce high voltages by cascading several of such units together has already been discussed. With the aid of Fig. 109, the method of obtaining a tension of one-million volts by connecting seven 150-KV units in series will be illustrated.

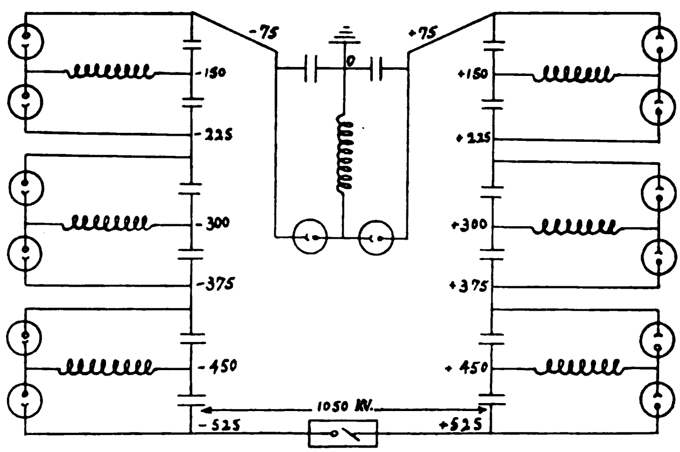


FIG. 109. CIRCUIT FOR OBTAINING ONE-MILLION VOLTS BY EMPLOYING SEVEN 150-KV GREINACHER UNITS.

Each unit is energized by a 75-Kv.P. transformer insulated from earth in accordance with its position indicated in the circuit by the kilovoltage values of the individual elementary circuits. For instance, the center unit is insulated for 75 KV to earth, the one next to it is insulated for 150 KV, and so on. The primary supply to these units is furnished through insulated 1:1 ratio transformers. The insulation between the primary and the secondary windings of each transformer is sufficient to withstand a potential difference of 150 KV or over. Also, 1:1 insulating transformers are employed to supply current to the primary of each filament-heating transformer, which is further insulated from earth for the respective potential as shown in the circuit.

A cascade generator built on this principle and producing one-million volts against earth has been developed by Kelley-Koett X-Ray Corporation, of Covington, Kentucky. Their scheme, however, embodies ten

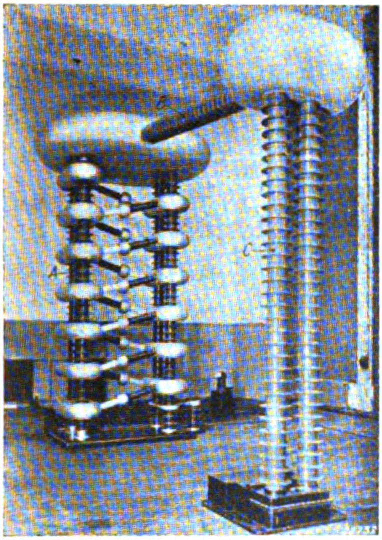


FIG. 110. BOUWERS' SIX-STAGE 1250-KV GENERATOR.

100-KV units, each containing a 50-Kv.P. tranformer.

(3) *Valve-Tube Cascade Generators In Excess of One-Million Volts.*—The principle of cascading Villard circuits to obtain high voltages limited only by the transformer output potenial has already been described in Sections (d) and (e). It will be now further observed that when the number of valve-tubes used is increased beyond four, a high-frequency method of filament heating becomes preferable from the standpoint of constructional simplicity, insulation of the equipment, and of preclusion of all accessory units.

In a comprehensive publication,* Bouwers and Kuntke have fully described the principle of Villard cascading for producing constant potentials ranging from 400 KV to 3000 KV. A 6-stage generator employing 12 rectifying valves to produce 1250 KV is shown in Fig. 110, and its circuit diagram is given in Fig. 111.

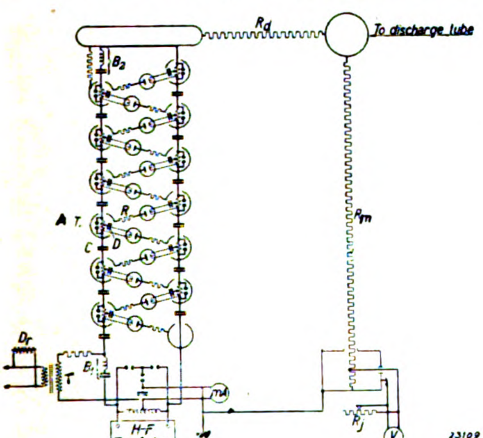


FIG. 111. CIRCUIT DIAGRAM OF SIX-STAGE GENERATOR FOR 1250 KV DIRECT VOLTAGE.

The unit employs an X-ray transformer T supplying a potential of 120 Kv.P. at 200 cycles, and 12 Philips gas-filled rectifying valves, each rated for an inverse voltage of 225 kilovolts. The condensers intermediate the valves have each a capacitance of $0.01\mu F$ (depending on the frequency of the current) at an operative voltage of 240 KV.

The filaments of the valves are heated from a high frequency valve generator furnishing approximately 8 watts to each valve-tube. This energy is transferred to each filament at a frequency of 500,000 cycles through a series-connected condenser *C* and a small auto-transformer *A.T.* inserted between consecutive condensers. A damping resistance *R* in series with the anode of each valve serves to prevent a possible short-circuit between the two groups of condensers on each side of the valve. A condenser *D* in series with one lead of each filament is employed to further

*Zts. Tech. Phys., Vol. XVIII, page 209, 1937.

prevent radio interferences that may otherwise be broad-cast from the apparatus. The lowest portion B_1 of the apparatus must be capable to sustain an insulation against 120 Kv.P. (the transformer potential), and the upper impedance B_2 to sustain against 1250 KV, the generator output. Two protective high-ohmic resistances are inserted on either side of the discharge tube (X-ray tube), as indicated in the diagram. The height of the room to hold such an apparatus must be at least 7.5 meters from the ground.

A cascade generator of this type with six stages, and measuring 5.5 meters high, has been supplied by Philips Metalix Corporation to the Cavendish Laboratory, Cambridge, for research in atomic physics under the direction of Lord Rutherford. The apparatus has been in operation for over two years at the time of this writing.

It is further claimed that by connecting two generators in series, one producing a positive potential of 1500 kilovolts to earth and the other a negative potential of equal magnitude, a potential difference of three-million volts has been realized. By increasing the number of stages, tensions as high as five-million volts (2.5 million volts negative, and 2.5 million volts positive to earth) should be feasible. The space required for such a generator, without supplementary screening means, must have minimum dimensions of 14 x 14 x 28 meters, as initially suggested by Bouwers.

5. Making Rectification Substitutions In X-Ray Circuits.—Not infrequently the question arises as to whether or not an X-ray rectification system can be altered from that of, for instance, full-wave to one of half-wave rectification, or vice versa. The answer will be affirmative, but with reservation.

It was already referred to on several previous occasions that each pulsation for a given half-wave current delivered to the X-ray tube is of a magnitude twice that delivered by a full-wave rectified current pulsation. In the case under consideration, then, the X-ray tube will receive for every half-cycle period of the current twice the milliamperage originally set forth for an exposure on a full-wave current. A tube which, for a given focal spot and a given exposure time, can take a current, for instance, of 150 milliamperes on full-wave rectification can not necessarily take 300 milliamperes at half the given exposure time, despite the same milliampere-seconds that are expended in both cases.

A tube designed to withstand low intensity uninterrupted pulsations (full-wave) when operated on a half-wave current of high-intensity interrupted pulsations will suffer a shorter tube life. This is because the temperature distribution of the focus metal is gradual, the application of a sudden high-intensity short-time pulsation will cause excessive local heating of the target surface receiving the cathode stream. Unless the tube is designed to safely withstand this extra load, it is entirely an infeasible practice to subject the tube to otherwise rigorous operations. On the other hand, a tube designed to operate on a half-wave rectification is not necessarily affected by being used on a full-wave current. Hence, it is urgently recommended that when making a change from one type of rectification to the other the primary considerations be first extended to determining the type of X-ray tube to be employed in the circuit under consideration.

In making alterations in the rectification system of a given X-ray generator circuit, the rectifying unit is first disconnected from the poles of the transformer secondary, and, after having substituted the new rectifying unit, the corresponding circuit terminals of the latter are connected to the respective transformer poles. The position of the X-ray tube may be re-adjusted, if necessary, so that its cathode is in the same phase as the incoming current from the rectifier (if there is any), viz., the negative lead from the rectifier should be connected to the cathode of the tube whereas the positive lead to the anode.

It will be obvious that in making a substitution in a rectification system, without changing the original X-ray tube, one would replace the original rectifying unit by one of nearest type. That is, if the rectifier output is pulsating, the new unit substituted should preferably be one of pulsating type; or, if the original rectification system puts out a constant potential current, the substitution should be of a type in accordance.

The maximum permissible loading time with a given kilovoltage on a given X-ray tube is found to be usually less for a constant potential current than for a pulsating type; and, for a half-wave pulsating current it is even less than for a full-wave pulsating type. These relations will be readily determined by a glance at the manufacturer's rating chart furnished with each X-ray tube.

QUESTIONS ON CHAPTER XII

1. (a) What is meant by "rectification" of a current?
   (b) By what general methods can rectification be accomplished?
   (c) Discuss self-rectification. On how much of a cycle does it function?
   (d) What factors control the emission of the cathode stream from the filament of an X ray tube?
2. (a) Give the circuit diagram and the voltage wave curve of a self-rectified apparatus.
   (b) Discuss fully the rectification of current by a mechanical rectifier, and then give the circuit diagram of the apparatus.
   (c) Give the advantage of mechanical recitfication over that produced by valve tubes.
   (d) State the function of a synchronous motor.
3. (a) Explain and illustrate how an autotransformer controls the input voltage to the X-ray transformer. Is there any loss of power (I^2R) in its winding?
   (b) What is a polarity commutator? Where is it attached in the X-ray circuit? How does it function?
   (c) How many revolutions does a polarity commutator make per second on a 60-cycle current? How many revolutions does it make per cycle?
   (d) Trace the current through the polarity commutator as it makes a complete revolution.
4. (a) Explain how a current rectification is accomplished by a Cuprous Oxide plate.
   (b) What physical drawback did early gas-filled valve-tubes present?
   (c) Describe a thermionic valve and discuss fully its mode of rectification.
   (d) What physical principles are employed to sustain stability in performance of thermionic valves?

5. (a) A thermionic valve is subject to produce X-rays. What factors contribute to the minimizing of this effect?
   (b) How does a high voltage drop in a valve tube affect the emission of X-rays?
   (c) What provision should be made to minimize the tension drop in a thermionic valve tube?
   (d) Explain fully the application of the principles characteristic of metal discharge chambers.
6. (a) On what two important factors is the life of a valve tube dependent?
   (b) Describe a Philips gas-filled rectifying valve, and fully discuss its operative characteristics.
   (c) Explain why oxide-coated filament cathodes are known as "dull emitters".
   (d) What significance is held by the inclusion of the thermionic valves in the high-tension circuit of the transformer secondary?
7. (a) Draw the circuit diagram of a single-valve unit, giving the approximate potential and current wave-forms.
   (b) On a half-wave current, why does the X-ray tube receive twice the milliamperage per impulse recorded by the meter?
   (c) To what practical value does a Villard circuit lend itself?
   (d) Explain the voltage-doubling properties of a Villard circuit.
8. (a) Of what practical value is constant potential in X-ray circuits? Discuss by an illustration how it can be obtained?
   (b) By what voltage will the depressed portion of a constant potential wave-curve differ from the maximum condenser potential, if the tube current is 80 M.A., the condenser capacitance 0.2 microfarad, and the fractional discharge time is 0.1 second?
   (c) Draw a two-valve full-wave rectification circuit and denote the direction of current flow by arrows: Give the wave form of the potential.
   (d) Describe fully the method of rectification and voltage-doubling in a Greinacher unit.
   (e) Differentiate a Garretson circuit from a Greinacher unit.
9. (a) Denote by arrows, the direction of current flow in a voltage-tripling (Witka) circuit.
   (b) Draw a four-valve bridge arrangement and insert a switch mechanism whereby the conversion of the system into a two-valve full-wave arrangement may be effected when desired.
   (c) Connect two Mutscheller circuits in series and denote by arrows the direction of current flow through the circuit.
10. (a) In a Bouwers' four-valve unit, show how the potential is built up to four times the transformer voltage.
   (b) What are the essential characteristics peculiar to 400,000-volt G.E. circuit employing XPT-4 Coolidge tube?
   (c) To what extent is a diagnostic apparatus equipped with six-valves is superior to the four-valve machine?
   (d) Five Greinacher units are connected together for obtaining 500 KV. Show by a diagram the connections and the voltage available across each unit. Also, state to what voltage each of the transformers is insulated against earth.
11. (a) Discuss the load characteristics of a three-phase six-valve circuit in relation to the radiographic quality.
   (b) Describe the manner of conduction of the three-phase current through the valves to the X-ray tube.

(c) What is meant by "ripplage"?

12. (a) What are the chief characteristics of an eight-valve Bouwers circuit? By what factor or factors is the X-ray output from this generator limited?

(b) In a Bouwers 800-KV circuit, if an X-ray tube is connected between the center of the transformer secondary and the terminal lead of one of the sectional circuits, how will the values of the kilovoltage and the milliamperage through the X-ray tube be affected?

13. (a) Cascade five Greinacher units to produce 750 KV; and, state to what potential should each unit be insulated from ground.

(b) Draw the diagrom of a 1250-KV Bouwers circuit, and fully explain its mode of operation.

14. (a) In an X-ray laboratory, it is desired to replace the half-wave mechanical rectifying unit by a set of four valve-tubes to give full-wave rectification. Explain, what changes and connections are to be made?

(b) What changes should be effected in substituting a half-wave pulsating rectification unit for a constant potential type?

CHAPTER XIII

X-RAY TUBES

Long before X-rays were discovered, the phenomenon of electric discharge through rarefied gases was known. Partially evacuated glass tubes having two sealed-in electrodes were subjected to relatively high voltages, furnished by an electrostatic machine, or by an induction apparatus, to produce an electric discharge characterized by the familiar apple-green fluorescence of the glass walls of the tube. But, such an endeavor did not bear any practical significance more than presenting an experimental diversion, rather whimsical, among the then "white-wigged" scholars of the scientific world.

An improvement on the first discharge tube consisted of a modified anode design and of producing lower pressures. A tube of this type, first built by Geissler, generated a radiation from the cathode that had the characteristics of cathode rays of lower energy. Soon after the appearance of Geissler tubes, further development of more improved discharge tubes advanced so rapidly that the English physicist, William Crookes, produced, about 1879, a highly exhausted cold-cathode tube, which opened new fields for investigations in chemical, electrical, and spectroscopic realms, and lay the basis for the discovery, by Roentgen, of an entirely new radiation, known as *X-rays,* from the tube. The introduction of this tube marked the first stride in the advent of the development of the ever-hailed modern high-powered X-ray tubes.

The chief objects of modern development, in general, have been directed toward providing safety, efficiency, and simplicity in X-ray equipment, by conforming to the highest standards of design and construction. Other objects of this movement have resided in the introducing of automatic methods for controlling the radiation intensity of X-rays, studying the problems of specific load capacity of the X-ray tube, providing adequate means for cooling the tube target, and finally obtaining the optimum radiographic quality by the extension of the rotating anode X-ray tube to taking instantaneous radiographs of the moving viscera.

Recent demand for high tension has led to the development of vacuum-sealed therapy tubes withstanding 400 kilovolts or over for use in the treatment of malignant diseases. Special research tubes energized by tensions of the order of one-million to five-million volts for experiments on transmutation of atoms are but modern adaptations of the early alchemist's attempt to convert one element into another. In the accompanying sections, our subject will especially be confined to discussions of the better controllability and of the use of X-ray tubes in reproducing conditions governing the diagnostic quality of radiographs, and in producing optimum results in X-ray therapy and technic.

1. Classification of X-Ray Tubes.—Constant improvements in the manufacture and design of X-ray tubes have given rise to two general types

of X-ray tubes now universally in use. The first and older type is known as the *ionic* or *gas-filled tube,* and the second and more modern type is the *vacuum* or *electron tube.* Though the second type is more generally used world-over, the gas-tube still finds wide application especially for scientific research purposes, as the radiation quality from it is more uniform and more stable than the electron type.

X-ray tubes, in general, are classified into the following arbitrary categories, which are only relative, as any one tube in one class may be used interchangeably for one in another class of neighboring kilovoltage capacity.

Class of Tube	Kilovoltage Rating	Type
1. Superficial Therapy, or Granz Ray	8 – 20	Electron. Ionic.
2. Crystallography	20 – 60	Electron. Ionic.
3. Diagnostic	35 – 110	Electron. Ionic.
4. Dermal Therapy	90 – 140	Electron. Ionic.
5. Radiography In Metal Industry	100 – 600	Electron.
6. Deep Therapy	200 – 1500	Electron.
7. Radiography of Concrete Construction	300 – 800	Electron.
8. Special Research	1000 – 9000	Electron. Ionic.

Each class of tubes is further divided into various sub-classes of modified constructions and of specific uses. But we shall confine ourselves to the study of the modifications of only that class for which occasion permits for detailed discussion.

2. The Gas-Tube (Ionic).—Following Roentgen's discovery, the first X-ray tubes to be developed for general use were gas-tubes. The use of this type of tube is still prevalent both in America and in Europe, in view of the fact that X-rays of more homogeneous character and hence purity in the spectrum are realized from them for work in analytical crystallography. Though the electron tube has superseded the gas-tube in medical and industrial realm, nevertheless, the latter tube (when used under controlled conditions) remains with distinct advantage in certain phases of X-ray applications.

The type of tube with which Roentgen made his famous discovery is diagrammatically represented in Fig. 112. The tube had, at one end, a flat disc C for *cathode,* and an *anode* A in the form of a straight wire sealed in a small glass side arm S. Cathode rays, impinging upon the glass wall of the opposite end T of the tube, gave rise to intense fluorescence, and the X-rays thus produced passed through the glass. Since the

new radiation was emitted from the entire rear wall area of the tube, radiographs made with this tube were somewhat blurred and lacked definition.

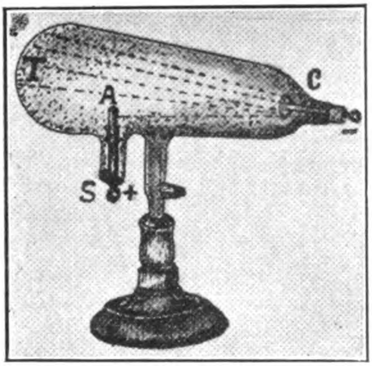


FIG. 112. FACSIMILE OF THE FIRST X-RAY TUBE.

Because the tube did not survive prolonged exposures, further improvements were necessary; and, as a result, a tube using a flat platinum disc anode mounted at an angle opposite a concave cathode was developed.

Still further improvements gave rise to the introduction of an *anti-cathode* (electrically connected to the anode), whose *focal plate* was re-enforced with copper to insure better heat conduction. A *vacuum-regulating device* consisting of a few layers of mica, or granulated charcoal, was provided for automatically adjusting the gas pressure inside the tube during operation. With this model, shown in Fig. 113, further development of gas tubes practically ended, with the exception of a few refinements devised to improve the radiographic quality and to increase the load capacity of the tube have been made all along up to the present day.

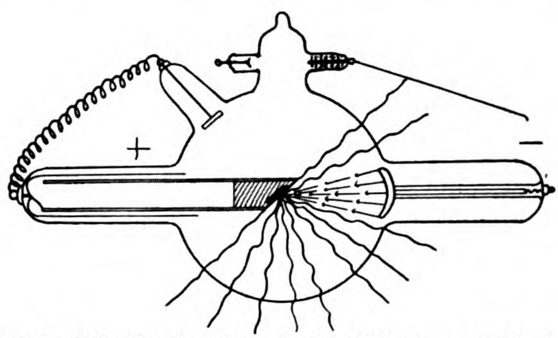


FIG. 113. THE GAS-TUBE WITH AN OSMOTIC REGENERATOR.

The gas-tube is an ionic tube in character. After having highly evacuated the tube, a minute amount of inert gas, such as Nitrogen, or Carbon Dioxide, is deliberately allowed to be absorbed by the charcoal or asbestos regenerator in the side tube during processing, raising the tube pressure between .001 to .01 mm of mercury. When a high voltage is applied to the tube, the residual gaseous molecules dissociate into *electrons* and *positive ions,* which, upon bombarding the cathode, cause further liberation of electrons from it. These electrons constitute the *cathode rays,* whose quality and speed are dependent upon the impressed voltage. The swiftly moving cathode rays, upon their impact on the anti-cathode or the target, produce *X-rays.*

The cathode of the tube consists of an Aluminum, or Molybdenum, rod with an enlarged terminal having a concave surface which serves to focus the cathode rays on the center area of the anti-cathode. Cathodes made of

Calcium have been successfully used in producing a smooth running discharge, permitting the tube to be run with safety at much higher tensions than that afforded by an Aluminum cathode.

All gas-tubes are operated on a rectified unidirectional potential, as otherwise the discharge will alternately shift to the anode and to the cathode, defeating the X-ray-producing properties of the tube.

The penetrating quality of the X-rays generated in a gas-tube is determined by the amount of residual gas. The less pronounced the pressure of the residual gas, the "*harder*" or more penetrating are the X-rays so produced. As the amount of the available gas in the tube diminishes by use, due to leakage at the joints, adsorption on the glass walls of the tube, etc., a small quantity of fresh gas is continuously admitted into the bulb to compensate for this reduction.

This is done by heating the gas *regenerator* by means of a high frequency discharge, which allows the gas to be diffused through a thin metal into the bulb proper, thus securing a constant gas pressure inside the tube. Because of the variation of the tube pressure and hence in the amount of ionization of the residual gas, the voltage, which controls the hardness of the X-rays, can not be varied independently without affecting the current through the tube.

During operation of the tube, the glass walls in the neighborhood of the cathode become highly charged with negative static electricity, while the main body of the tube becomes positively charged. The effect may cause the *focal area* to vary capriciously and to wander to such an extent as to produce a tendency for a discharge to pass along the glass walls. Hence, the provision of a straight wire Aluminum anode located somewhat behind the anti-cathode is to obviate the effect, and to reduce the cathodic sputtering markedly.

The targets of the most recent gas-tubes used for diagnostic work consist of a Tungsten button welded to the target surface of a massive Copper stem constituting the positive electrode. The purpose of employing Tungsten for the focal area is to secure a large output of radiation, and to avoid vaporization of the focus metal onto the walls of the tube, while Copper, due to its excellent heat conductivity, reduces local heating of the target.

Some of the modern research gas-tubes have such an improvement over the old type tube that they are competing quite favorably with the electron tube. Shearer, Siegbahn, Müller, Bouwers, Becker, and others, have constructed metal tubes with targets interchangeable for different radiographic technics. The targets of these tubes usually consist of one of Iron, Molybdenum, Cobalt, Copper, or Tungsten. The gas pressure inside the tube is automatically regulated by special connections between the tube and the vacuum pump permanently connected to the former. Thin foil windows, and a special water-cooling system add to the efficiency of the tube. Since from these tubes a high degree of purity in the radiation quality is attained, most spectroscopic and crystallographic work is done by means of gas-tubes.

Owing to the rugged construction of these special tubes, they can be operated at high load capacities, and hence the quantity of radiation is so unusually increased that radiographs can be made in much shorter times than those normally required. Some of these tubes are so constructed

that they are self-rectifying. Of these, the Shearer tube is believed to be one of the very original in design and construction.

3. The Electron Tube (Vacuum).—It has already been observed that the production of electrons in a gas-tube occurs as a result of *ionization* of the residual gas *by collision*. Since the magnitude of the ionization and the velocity of the electrons are dependent on both the residual gas pressure and the potential applied to the tube, a complete control over the intensity and the penetration quality of the resulting X-rays independently of each other has not been practicably possible to achieve. This is particularly due to the instability of the tube pressure, a slight change in which greatly affects the quantity of electron discharge across the X-ray tube. Owing to the difficulties thus encountered, recourse was made to the development of a new type of X-ray tube with more stable electron discharge properties.

The new departure is a high vacuum tube having a hot cathode which furnishes the necessary cathode rays. The commercial application of the principles of *thermionic emission* in X-ray tubes was first announced by W. D. Coolidge in 1913, three years after his announcement of a successful method of producing ductile tungsten. The cathode of the present vacuum tube consists of a spiral tungsten filament surrounded by a cylindrical shield of sheet molybdenum, which insures the focusing of the electrons on the anode. The target which receives the impact of the electrons projecting from the cathode is made of a solid block of copper with a small tungsten disc, known as the focus metal, set into the center of its surface facing the cathode at an angle between zero and 84 degrees with the vertical. The magnitude of this angle varies with the type of the X-ray tube; and, ordinarily for diagnostic work it is about 10 to 20 degrees.

The *emission* of electrons from the cathode is dependent on the *temperature* of the *filament*. The higher the temperature a greater number of electrons will be emitted. The more electrons are desired to be drawn, within limits, to the target, correspondingly a higher tension is applied to the X-ray tube. The impressed voltage further determines the speed with which the electrons will collide with the anode. Hence, the quantity of the milliamperage across the X-ray tube is dependent both on the temperature of the filament and on the potential driving the electrons.

Practically all of the electrons in the cathode ray bundle strike a limited area (varying from 1 sq. mm to 1 sq. cm.) on the target surface, called the *focal spot*, which is usually visibly defined as an etched area. The size of this spot is determined by the shape and extent of the filament incorporated in the molybdenum *cathode shield*, and by the distance of the filament from the anode. The smaller the focal spot, the power applied to the X-ray tube will be correspondingly reduced. But, radiographs produced with a *fine-focus* tube possess sharper definition of detail. The density of the radiograph, however, is independent of the size of the focal spot.

The distinct advantage of the electron tube over that of the gas-tube is that the electron emission — and hence, the milliamperage through the X-ray tube — can be accurately controlled by the temperature of the cathode filament, whereas the quality (hardness) of the X-ray emission can be controlled to a high degree by regulating the impressed tension

on the tube. That is, the intensity and the penetration quality of the X-rays from an electron type X-ray tube can be controlled independently of each other. By means of this new development, load capacities ranging from 2.5 to 200 kilowatts are easily obtainable, while the load capacities of old type gas-tubes seldom have exceeded one kilowatt.

Fig. 114 illustrates the relative magnitudes of the current and voltage to heat the filament of the X-ray tube; and Fig. 115 shows the relation of the filament heating current (temperature) to the milliamperage through the X-ray tube.

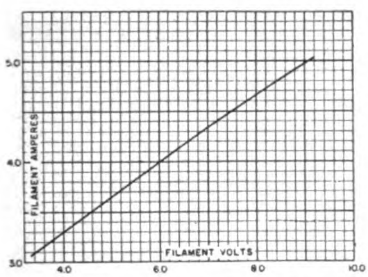


FIG. 114. FILAMENT CURRENT AGAINST FILAMENT VOLTAGE.

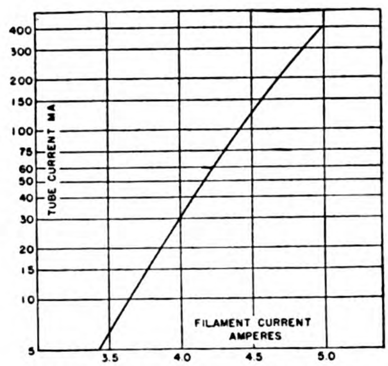


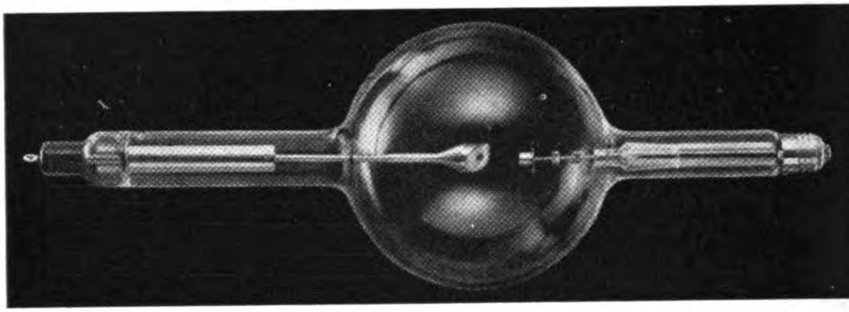
FIG. 115. FILAMENT AMPERES AGAINST TUBE MILLIAMPERAGE.

The modifications of the modern electron type X-ray tube are numerous and varied. Among these are included tubes with various focal spot shapes and sizes, stationary and rotating-anode tubes, non-shock proof and shock-proof tubes, non-ray proof and ray-proof tubes, and tubes having radiators, water-coolers, or oil, for their cooling systems. One single tube of any of the above constructions may be so designed as to afford its use for more than one purpose. These tubes may be classified, in general, into the following four types, which embody the scope of this text: *The universal tube, the diagnostic tube, the deep therapy tube, and the oil-immersed dental X-ray tube.*

(a) *The Universal Tube.*—The earliest X-ray tube that employed an incandescent filament for producing electrons was essentially of this design. Owing to the fact that a single tube of this type serves, where necessary, for radiography, fluoroscopy, and therapy, it has become known to the radiological world as the Universal type.

The Coolidge Universal X-ray tube consists of a glass envelope, 21 inches long, with central bulb enclosing the cathode and the anode. The cathode has a spiral tungsten filament welded permanently to the apex of an electron-spreading cone, which is surrounded by a molybdenum focusing shield to direct the beam of cathode rays to an accurately predetermined area on the target. The target (anode) is of solid tungsten, and during operation of the tube, it becomes heated to incandescence, since no direct provision is made for carrying the heat away from the metal. Obviously then, only metals that are suitable for the purpose of withstanding high temperatures without melting are used in the anode construction. These

metals are, for instance, Platinum, Thorium, and Tungsten. Tungsten is adopted universally as the target material because of its having a high melting point, high atomic number, and low vapor pressure.



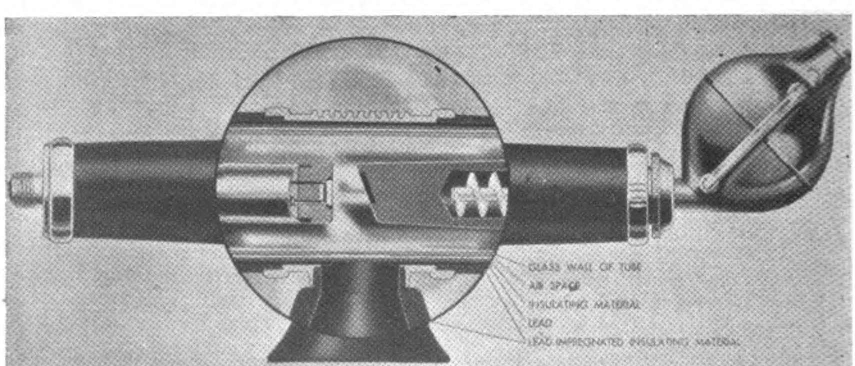
(COURTESY GENERAL ELECTRIC X-RAY CORP.)

FIG. 116. A UNIVERSAL TYPE X-RAY TUBE.

This type of tubes are designed primarily to operate on rectified current only, since both electrodes are hot, and, therefore, are sources of electrons. While the tube may be operated with small impressed loads over long periods of time, as in fluoroscopy and superficial therapy, it is seldom used for radiographic work of considerable volume, in view of the adaptation of the line-focus design for this latter purpose.

A Universal tube is generally air-cooled, and the type shown in Fig. 116 operates continuously at 140 Kv.P. and 5 M.A., and at 85 Kv.P. and 8 M.A. The filament is rated at from 3.5 to 5 amperes for a tension of 4 to 8.5 volts. A more recent model, due to the incorporation of the cathode filament in a hemispherical shield — and hence, the realization of a better control of the cathode rays — has a continuous current rating of 6 M.A. at 200 Kv.P. The tube measures 34 inches, and lends itself to deep therapy X-ray applications.

(b) *The Diagnostic Tube.*—For intermittent use, such as in diagnostic work, a radiator type tube is found to be more preferable. The G.E. Cool-



(COURTESY GENERAL ELECTRIC X-RAY CORP.)

FIG. 117. WATER-COOLED XP COOLIDGE DIAGNOSTIC TUBE.

idge diagnostic tube is provided with one of the two types of cooling systems—air-cooled radiator type, and water-cooled type. In view of the interchangeability of the two types of cooling units, conversion from the air-cooled to the water-cooled type may be made where some special type of work calls for rapid cooling.

Fig. 117, below, represents a water-cooled type ray-proof Coolidge tube sectioned to show the internal construction of portions of the filament, the anode, and the spiral baffle device in the cooler. With the latter device the violent boiling of the water immediately behind the anode face is obviated. It is quite obvious that if this baffle device is eliminated from the cooler, the tube will be subjected to unavoidable vibrations, by the violent boiling of the water, during an exposure, affecting radiographic detail.

Completely surrounding the tube is an X-ray protective shield (equivalent to 1/16 inch of lead), the central portion of which consists of a lead cylinder to intercept all direct radiations except that confined to the X-ray portal. A further function of the protective shield is to minimize the danger of accidental breakage of the tube envelope, to furnish the tube with an added mechanical strength, and to protect it against puncture in case of a spark-over. When the tube is operated with its protective shield the maximum impressed tension ranges up to 110 Kv.P., while without the protective shield the rating is reduced to 100 Kv.P.

The cathode of the tube consists, as usual, of a concave molybdenum focusing element incorporating a tungsten filament in an oblong focal cup in the center of its concave surface. Through this cup the electrons are projected toward the anode and focused on the focal spot. The shape, size, and the depth of the cup, and the size and position of the filament in this cup, determine the focal spot area on the target. The proper spacing between the two electrodes also directly affect the size of the focus.

The *anode* of the tube is a block of copper whose target surface usually makes a 20 *degree angle* with the vertical. Since the heat conductivity of copper is approximately three times that of tungsten, the provision of a massive anode insures rapid conduction of heat to the cooling unit. The ability of a cooler unit to dissipate the heat from the hot target determines the frequency with which exposures may be made over any given period of time. For moderate amount of diagnostic work, a radiator type cooling is very satisfactory, while for more frequent exposures the water-cooling is unexcelled for a tube with stationary anode.

The focal spot breadth of an ordinary diagnostic type tube varies from 0.5[1] mm to 5.2 mm. The area of the focal spot varies from 1 sq. mm to 70 sq. mm. One general type of line-focus tube has a focal-area of 16 sq. mm.—2 mm wide, and 8 mm long—and the effective focus as projected from a 20 degree target is 2 mm square. The X-ray energy at the effective projection is then approximately three times that of the X-ray intensity of the entire radiation. Owing to the elongated shape of the focus, the term "*line-focus*", or "*Benson focus*" (after its designer), is applied.

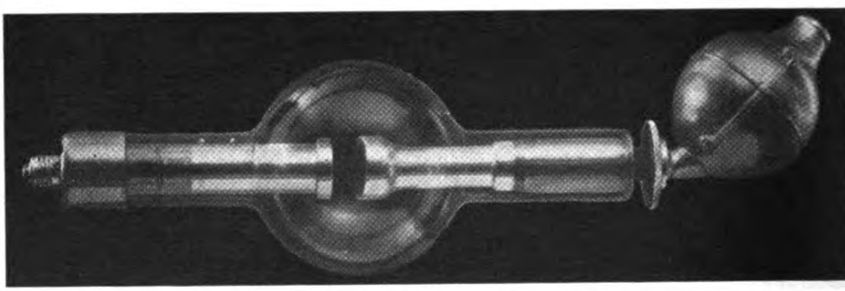
Practically all diagnostic X-ray tubes of recent manufacture embody the line-focus design. Within the load limitations of the radiator tube the

1. See, A. Bouwers, Brit. J. Radiology, Vol. VII, p. 21, 1934.

target never becomes sufficiently hot to provide an independent emission of electrons from its surface. Thus, the tube makes itself valuable as a self-rectifying unit for portable apparatus, and for oil-immersion self-contained dental equipment.[1-2]

Another modification in the series of bulb-type Coolidge tubes is the water-cooled model 10-RW, shown in Fig. 118. This model, specifically designed for heavy-energy short radiographic exposures, is capable of operating at 85 Kv.P. and 1000 M.A. for 1/30 second, or 50 Kv.P. and 500 M.A. for ½ second, despite its effective focus which is only 5.2 mm square. The tube is further capable of handling 2000 of these exposures in one 8-hour day.

The face of the target is inclined at an angle of 80 degrees to the tube axis; and, the filament is rated from 5.5 to 9.5 amperes for a potential drop of 5.5 to 15.0 volts. The overall length of the tube with cooler is 26-7/8 inches.



(COURTESY GENERAL ELECTRIC X-RAY CORP.)
FIG. 118. WATER-COOLED 10-RW COOLIDGE TUBE FOR HIGH POWER SHORT-EXPOSURE RADIOGRAPHY.

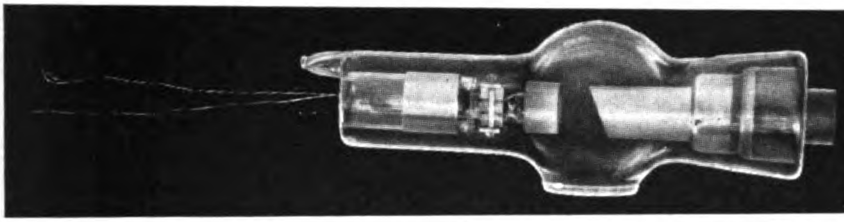
(c) *Oil-Immersed Tubes.*—Model CDX Coolidge dental X-ray unit, first made commercially available in 1923, enjoys the advantage of oil-immersion principles by having both the high tension transformer and the X-ray tube immersed in a pure mineral oil base and hermatically sealed and grounded in one common container. The apparatus is compact and offers 100% electrical safety. Because of the isolation of the X-ray tube from the surrounding atmosphere a more consistent tube performance at relatively hard load conditions is achieved. With oil-cooling of the X-ray tube, shorter anode arm design with smaller bulb construction becomes possible. An X-ray tube of this character, having a lead glass envelope, is rated at 68 Kv.P., and 10 M.A., operating as a self-rectified unit. It incorporates a line-focus of 1.5 mm on a 20 degree anode face. The envelope portion at the point of emergence of the rays is ground down to a reduced thickness so as to decrease the amount of absorption by the glass. In some tubes this portion of the envelope is provided with soft glass window.

Other models of hard glass tubes lend themselves admirably to voltages up to 100 Kv.P. for 30 M.A. The principle of oil-immersion is also adopted in numerous other diagnostic and therapeutic equipments for operation

1. CDX-Dental Unit, by General Electric Co.

2 See, A. Bouwers, Brit. J. of Radiology, Vol. VII, p. 21, 1934.

at tensions of the order of 400,000 volts, and over. A form of model CDX Dental X-ray tube is shown in Fig. 119.

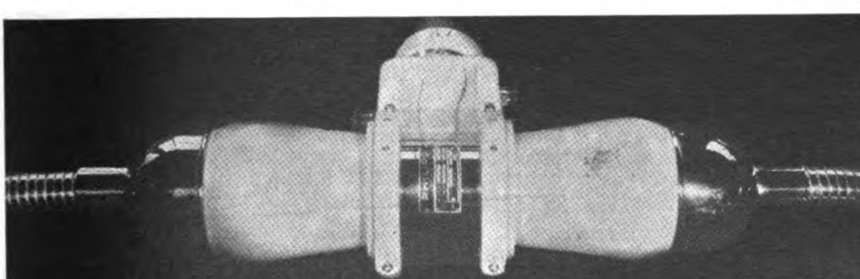


(COURTESY GENERAL ELECTRIC X-RAY CORP.)
FIG. 119. OIL-IMMERSED COOLIDGE DENTAL X-RAY TUBE.

Oil-immersed X-ray tubes are also constructed with *rotating-anodes,* and with *double-focus* features in the case of tubes with *stationary anodes.* The rotating-anode type, however, offers the advantage of the application of considerably higher X-ray energies to relatively smaller focal spots.

(*d*) *X-ray Therapy Tubes.*—The *deep-therapy tubes* are used in the treatment of cancer, ulcers, tumors, carcinoma, or other malignant diseases. These tubes are energized ordinarily with voltages ranging from 200 Kv.P. to 800 Kv.P., that the wave-lengths of the X-rays thus produced overlap, in spectral series, the longer wave-length gamma-radiation from Radium C.

In this type of tube, a circulating liquid supply (oil or water) contained in an independent reservoir serves for cooling the anode. Tubes available for use at continuous ratings of 200 Kv.P. to 300 Kv.P. with 10 M.A. to 30 M.A., respectively, are provided each with a tungsten target backed by copper, and further provision is made for circulating the cooling-liquid either by a thermo-cyphon or a pump. The advantage of employing oil over that of water for cooling the target is that insulation of the coupling connecting the pump with the driving motor is not necessary. In Philips Metalix water-cooled therapy tubes, the provision of a grounded Chromium-Iron cylinder at the central discharge chamber makes possible highly effective ray-proofing at this portion. The tube, shown in Fig. 120, is rated at 200 Kv.P. and 12 M.A., with a filament characteristic of 3.5 to 4.2 amperes at 7 to 10 volts.

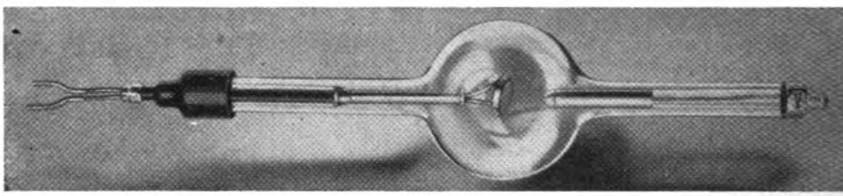


(COURTESY PHILIPS METALIX CORP.)
FIG. 120. WATER-COOLED METALIX 200 KV.P., 12 M.A. THERAPY TUBE.

Owing to the fact that the center metal cylinder of the tube is grounded, filters or cones may be attached directly to the tube at extremely short

focus-skin distances (as small as 65 mm) without fear of electrical shocks. This tube is specifically designed for deep therapy work. The X-rays from it are generated within a hooded anode which offers an inherent filteration value equivalent to 1.0 mm aluminum. Extensions of lead glass cylinders on each side of the metal discharge chamber afford additional protection against stem radiation from the tube.

About the same time that Metalix shock-proof 200 Kv.P. therapy tube was introduced in 1920, the first water-cooled Coolidge XPT tube of similar rating, shown in Fig. 121, was announced by General Electric Company. It is claimed that the X-ray intensity of this tube is about six times that of an ordinary spherical glass-bulb type tube. The design and the construction of the tube-stand permit the positioning of the tube at every



(COURTESY GENERAL ELECTRIC X-RAY CORP.)

FIG. 121. WATER-COOLED COOLIDGE XPT THERAPY TUBE RATED AT 220,000 VOLTS AND 30 M.A..

practical angle with 100% electrical safety and full X-ray protection. As a means of extreme flexibility in X-ray therapy dosage, the installation of four such tubes, controlled from a central station, affords the simultaneous multiple port treatment of one patient from all four tubes *"cross firing"*; two patients from two tubes each, or four from one tube each, since these units may be energized independently of each other. Six of such units may be energized by one generator of 220 kilovolts and 30 M.A. capacity, and cooled by G-E Oil-Cooling units. The unit, without a doubt, is one of the most practical high-voltage therapy tubes yet devised to be successfully applied in the treatment of malignant diseases.

A sealed-off roentgen therapy tube for use at 400,000 volts constant potential with ray-proof construction was made available in 1934. One type of this rating, manufactured by Philips Metalix, embodies shock-proofing features of tubes of lower energy ratings. Owing to the provision of a grounding connection from the metal discharge chamber the possibility of incomplete shock-proofing is materially reduced. A therapy tube of same rating and tested at 500,000 volts constant potential is introduced by General Electric. The tube, shown in Fig. 122, is designated as XPT-4 and has an overall length of 60 inches. It is designed for operation in air at a tension of 400,00 volts. The energizing equipment is *"center grounded"* so that spacings for only 200,000 volts to earth are required.

A distinct feature of the XPT-4 tube is its anode construction differing radically from other therapy tubes of lower tensions. The target end of the anode is supplemented by a *hollow cylinder of copper*, which prevents the rebounding electrons (stray electrons) from the tungsten target from reaching the glass envelope and charging it to a negative potential. Thus, the extraneous electrostatic stresses, prominent in tubes of other designs,

are precluded from the envelope, which is made of *borosilicate glass* of one-quarter inch thickness. Owing to its relatively small size, the XPT-4 tube is adaptable to self-contained portable type of equipment for use in

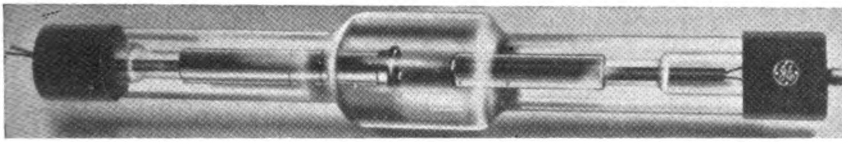


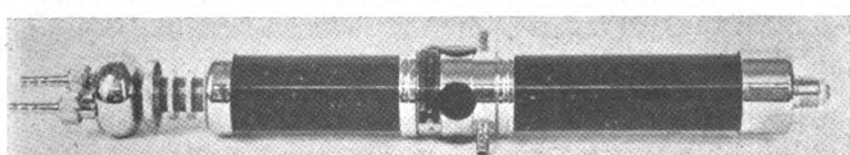
FIG. 122. COOLIDGE XPT-4 THERAPY TUBE RATED AT 400,000 KILOVOLTS.

industrial roentgenography. A self-rectified therapy tube of same rating is develped in 1937 by General Electric Company.

Another deep therapy unit of prominence is the Siemens-Pantix tube, recently introduced to operate at 400,000 volts effective and 5 M.A., which embodies a rounded cathode structure and a shielded target for inclosing the trajectories of stray electrons. Protective rings built on the outside termination of each electrode make it possible to reduce the overall length of the tube materially.

4. X-Ray Tubes Of Special Construction; Research Tubes.—Among some of the latest developments in X-ray tubes is the high current capacity Philips Metalix tube constructed according to the *"principle of restricted range,"* which assigns spherical configurations to the cathode and anode surfaces. The cathode filament consists of a few turns of tungsten wire, from which the electrons project into the conical recess in the target. Owing to the gradual convex curvature of the cathode and the corresponding concave curvature of the anode, the elimination of cold discharges due to prevalent field density and the preclusion of secondary and stray electrons from the glass envelope are realized.

For crystal analysis by differaction methods, which generally require monochromatic X-radiation, Philips Research Laboratories further offer tubes in a choice of five different target materials—Copper, Cobalt, Iron, Molybdenum, and Tungsten. Of these, copper is suitable for most cases, while a cobalt target is especially recommended for the examination of irons, and steels. For experiments requiring a continuous spectrum, a molybdenum or a tungsten target is preferable, the former having the advantage that the tube may also be employed as monochromatic X-ray generator. A zirconium filter may be used with a molybdenum target, nickel filter with

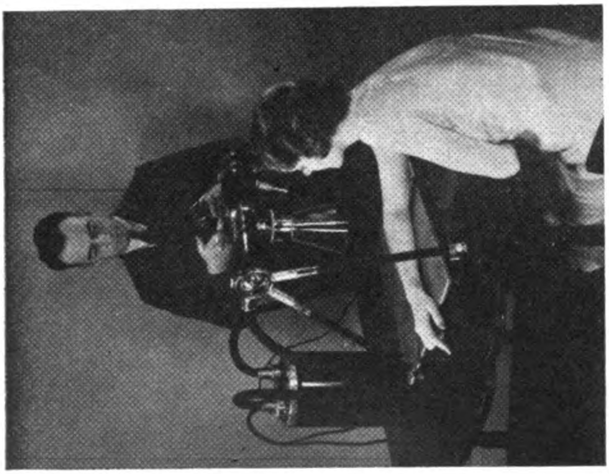


(COURTESY PHILIPS METALIX CORP.)

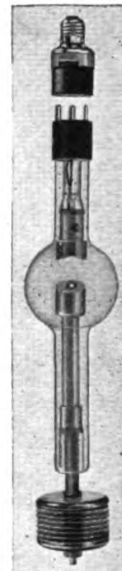
FIG. 123. PHILIPS METALIX RESEARCH TUBE.

copper target, and a manganese filter with iron target, for obtaining practically homogeneous radiation. A typical Philips Research Tube is shown in Fig. 123.

PLATE IV

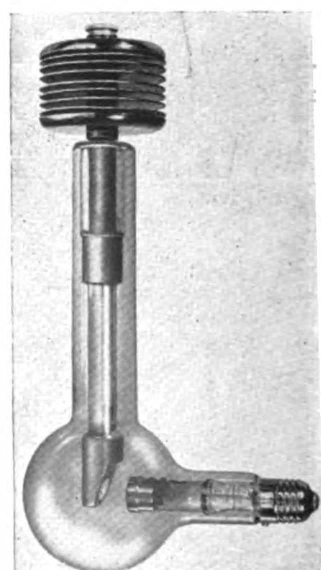


PHILIPS-METALIX PORTABLE X-RAY APPARATUS.



EUREKA DFL 100 AL X-RAY TUBE. DOUBLE FOCUS; 1.5 AND 3.5 MM. 110 KV.P. MAXIMUM.

EUREKA 100 P. PROTECTIVE X-RAY TUBE. ENCLOSED IN RP SHIELD WITH ADAPTER. 90 KV.P MAXIMUM.



EUREKA 4-70 RAL - RIGHT ANGLE X-RAY TUBE. 1.5 MM 70 KV.P. 70,000 HEAT UNIT.

These tubes are highly evacuated and are provided with cross-focus construction. Because the center metal of the tube is grounded, four cameras may be mounted close to the Lindemann glass* windows and at about 10 degrees with the target surface. The anode is kept cool by forced water cooling; and, the tube operates at 50 Kv.P. with both the metal center and the anode grounded, and at 70 Kv.P. with metal center grounded but the anode insulated from ground.

A unique tube developed by Müller possesses the characteristic feature of automatically varying the target focus. In the center of the spiral filament is a metal rod sustained at a more negative high tension in respect with the filament, to which is connected a high resistance in series. In accordance with the relative potential difference between the filament and the rod the bundle of cathode stream projecting from the cathode cup will vary in diameter, thus changing the area of the focus. The device, then, functions as a fine-focus tube or as a broad-focus tube determined by the magnitude of the milliamperage to be passed through it.

For dental radiography, where bringing the tube close to the patient's face frequently becomes desirable, an X-ray tube with electrodes at right angles has been constructed by General Electric. Designated as Model RA-2, the anode of the tube has a 20 degree angle and incorporates a line-focus with an effective projection of 1.5 mm. The cathode end of the tube having been earthed, close approximation of the tube to the patient's face may be afforded with safety. Rated at 63 Kv.P., 10 M.A., and 75 seconds, the tube offers the realization of fine radiographic detail of high diagnostic value.

To do away with the deleterious effects of stem radiation, Westinghouse engineers have developed a radiographic tube in which a cylindrical cathode encloses the anode, and the filament is constructed parallel to the target face. X-rays from the target pass back through the ring filament and emerge at the cathode end of the tube.

Hot-cathode gas-filled tubes employing Neon, or Helium, and having the operation characteristics of an electron tube and with increased radiation density are produced. Because the inert gas does not disappear with use, the tube pressure, and hence the operation of the tube, remain constant throughout the tube filament life. Müller tubes of this type contain Helium, whereas Neon is employed in those of Westinghouse brand.

Continuously evacuated tubes for deep therapy and special research work are now available through Philips Metalix, General Electric, Metropolitan Vickers Company, and various other manufacturers of X-ray equipment. These tubes are also privately built in various university research laboratories; some of them are constructed with high-intensity rotating-anode features operable at power energies as high as 200 kilowatts that exposures as short as 1/200,000 second are made possible. In spectroscopic investigation of wool, exposures, requiring as high as two hours or over with an ordinary tube, are reduced to a few minutes, and the quality of radiographs thus produced is sharp and well defined. Owing to these short exposure times, the study of materials such as paraffins, potassium tri-

*Lindemann glass contains Boron, Lithium, and Beryllium, unlike ordinary glass, which contains Sodium, Silicon, Calcium, and sometimes Potassium.

iodide, unstable alloys, mercerization processes, etc., which are affected by warming up through prolonged radiation from other types of tubes, have been realized without decomposition or disintegration of the specimens under investigation.

Many of these tubes have demountable targets, and one described by A. Bouwers of Philips Metalix surmounts the complications presented by other tubes in that no ground joints or greasing is necessary in mounting the anode to the tube proper. Special rubber ring cushions produce air-tight connection between the stem of the anode and the glass envelope. Mercury-diffusion pumps in conjunction with liquid-air traps are used throughout the evacuation process of these tubes.

Interest has been directed within the past few years toward high-voltage X-ray generating equipments for special research work. Of these, one of the first to be constructed for operation at 650 Kv.P. is that by Lauritsen and Crane at the California Institute of Technology; 900 Kv.P. (three stage) Coolidge cascade generator; 1500 kilovolts seven-stage Bouwers generator evolved from Cockroft and Walton cascade principle, and later this has been extended to the construction of a generator comprising 8 stages and having a negative potential of 2000-kilovolts to earth, with a current intensity of several milliamperes; 3000-kilovolt generator, developed by Lange and Brasch of Germany, producing X-rays that penetrate lead to a depth of one meter, and 7500-kilovolt surge generator in the process of construction by the same physicists; and, 5000-kilovolt X-ray generator at the Massachussette Institute of Technology.* These tubes are primarily devoted to the study of the ultimate structure of matter, and for cancer research, since the super-X-rays produced by latter generators are equivalent to thousands of grams of Radium, so important in the treatment of malignant diseases.

There are still various other X-ray tubes, but the ones introduced in this text serve to illustrate in a general manner the distinguishing features of the conventional apparatus in the light of present-day knowledge. For instance, several other types, such as X-ray protected, shock-proof, and rotating anode type tubes, will be taken up and described in separate sections.

5. The Design and Manufacture of X-Ray Tubes‡.—With the introduction of the Coolidge tube in the United States and that of Lilienfeld's in Germany, in the year 1913, both tubes employing hot-cathode emission principles, an important step in the X-ray tube development was launched on its way to success. While the new tube has surmounted the difficulties and complications presented in the erratic performance of gas-tubes, whose use now for diagnostic work has been gradually superseded, the problem of attaining the ideal X-ray tube has by no means been solved subsequent to the appearance of the hot-cathode tube.

*The school is constructing a 9,000,000-volt tube which will use electrons instead of X-rays to treat cancer. (May, 1940)

‡For more detailed information, the reader is referred to the following publications: M. J. Gross & Z. J. Atlee, of General Electric, Progress in Manufacture of X-ray Tubes:: Radiology, Oct., 1933, Vol. XXI, p. 365.
A. Bouwers & Colleagues: Philips X-Ray Research and Development, (1923 - 1937)
Westinghouse X-Ray Manual, 1935 Issue.

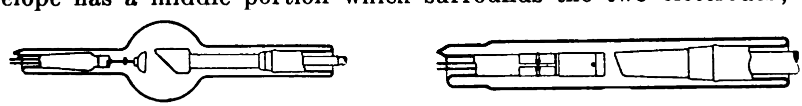
Because of the load capacities in excess of 10 to 200 times as great as that possessed by a gas-tube were made possible by the development of the electron tube, new problems presented themselves (1) in the provision of a means for the disposal of the tremendous quantity of heat generated at the anode, and (2) in the maintenance of the radiographic quality produced by fine-focus tubes of lower energy capacity, as an increase in focal spot size was necessitated with these high-power tubes. The cooling of the anode was affected by means of metal radiators or water-coolers incorporated into the anode stem of the tube. From improvements in anode design and the adequate choice of a cooling medium in an attempt to obtain more efficient heat dissipation has evolved the rotating-anode tube in 1929 through Philips Metalix Laboratories. Further improvements have given place to problems of ray-protection and shock-proofing, which have introduced other problems.

In the accompanying sections we shall present, as completely as space will permit, some of the governing factors in the development of X-ray tubes, with particular reference to more recent progress in design and manufacture.

(*a*) *Determination of The Physical Dimensions of An X-Ray Tube.*—Every X-ray tube of recent manufacture has predetermined dimensions which are largely a definite function of the maximum voltage and the milliamperage at which the tube is to be operated. Owing to the desirability of high velocity electrons in the production of X-rays, roentgen tubes present problems unencountered in any other type of vacuum devices, with the exception of high-voltage rectifier units.

In an X-ray tube, an atmosphere of electrons must be liberated at the cathode, projected at high velocities, focused to a small area on the target, and suddenly stopped by it. The kinetic energy ($\frac{1}{2}mv^2 = Ve/300$) of most of the electrons is transformed at the anode into heat energy, while a very small portion (less than 1%) is transformed into X-rays. Hence, the resultant heat must be dissipated. Furthermore, some of the electrons in the cathode stream after impinging on the focal spot rebound* at decreased velocities and hit the anode again all over the surface; some are attracted to the glass envelope, producing electrostatic stresses.

Two designs of the conventional X-ray tube are shown in Fig. 124. Each envelope has a middle portion which surrounds the two electrodes; and,



(A) SOFT GLASS TUBE. (B) PYREX GLASS TUBE.
FIG. 124. CONVENTIONAL DESIGN OF ELECTRON X-RAY TUBES.

two cylindrical extensions, which give support and, due to their relatively long length, prevent a flash-over between the electrode terminals external to the envelope. A further purpose of these arms is to preclude any appreciable amount of stray electrons from the glass adjacent the electrodes. The stray electrons, however, can be trapped in a cylindrical extension on the anode of those tubes that are adopted for high voltage; and, for lower tension tubes, the preclusion is insured by an ingenious method of

*See, Stray Electrons.

incorporating an earthed metal cylinder at the central portion of the envelope provided practically in all Philips Metalix X-ray tubes.

The central bulb design of Fig. 124a provides an effective cooling means in the case of Universal and air-cooled therapy tubes, and it further provides a surface for the deposition of metallic particles sputtered from the electrodes. Due to the remoteness of the bulb walls from the anode and cathode heads, disturbances that may arise from high tension electrostatic effects are thus obviated.

In some cases it becomes desirable to construct the glass envelope out of a cylindrical tubing as shown in Fig. 124b, due to the fact that an X-ray protecting sheath can be more readily placed around it. Since the arms of the envelope are of same diameter as its central *"bulb"* portion, sufficient internal tube spacing is provided to compensate for the bulbous portion and the constricted portions desirable for the prevention of excessive electrostatic stresses prevalent in the envelope of bulb type tubes. The lead sleeve of the X-ray protective cover produces a condenser effect in conjunction with the metallic electrodes, and the glass envelope as the dielectric between them. It also eliminates the longitudinal electric stresses in the envelope, thus materially improving the tube operation.

The *electrode spacings* in an X-ray tube must be consistent with the ability of the tube to operate at its maximum rated tension. Though it is highly desirable that the spacing between the anode and the cathode be as small as possible, too close a spacing will cause *cold cathode discharges* and hence erratic tube operation, while with a larger spacing difficulties are presented in the focusing of the cathode stream by reason of then increased distorting influence of the negatively charged glass envelope. The permissible variation of this spacing for a given tube occurs at a maximum plus or minus tolerance of 0.5 mm. Within this limit, no appreciable variation in the focal spot area or in its energy distribution is observable.

(b) *The Nature of The Glass Envelope.*—Practically in all X-ray tubes glass is expressly employed as an envelope material, because of its being transparent and good *electrical insulator,* and having relatively a *high dielectric strength, high melting point,* and *low X-ray absorption* properties. The last three are of particular importance from the standpoint of design and manufacture of X-ray tubes.

The early X-ray tubes were constructed of *soft glasses* of Sodium or Cerium with a Silicate base. Tubes of later manufacture employed *lead glass* and some employed exclusively *borosilicate* or *pyrex* glass. Most present-day X-ray tube envelopes are made of pyrex because of its great mechanical strength, high melting point, and high electrical resistivity. Various sealed-off X-ray tubes for deep therapy, for industrial radiography, or for special research work, carrying loads in excess of 400,000 volts have been built with envelopes of borosilicate glass or pyrex.

The prerequisite of an X-ray tube envelope is its withstanding very high potential stresses produced by stray electrons. These stresses are usually prevalent in two different directions in the glass. When a potential is applied to the tube, the inside surface of the envelope acquires a negative charge, and as a result, a difference of potential between the inner and outer surfaces is established. The phenomenon produces a *longitudinal*

stress along the ***inside surface of the glass*** envelope and a ***radial voltage stress between the two surfaces of the glass.*** The latter stress is usually the cause of ***tube puncture,*** which may be prevented by increasing the thickness, and hence the dielectric strength, of the envelope. The tube failure may further be prevented by providing a means for trapping the stray electrons, as has already been discussed in a previous section.

In diagnostic tubes, the envelope thickness is more than sufficient to withstand tensions in excess of tube rating. In some tubes, the portion of the glass envelope through which the useful X-ray beam becomes emergent is ground down to as low as one-fourth its original thickness. While this reduces the filtering action of the glass, the mechanical strength of the envelope is not altered to any appreciable extent. The General Electric XPT-4 roentgen therapy tube, shown in Fig. 122, has borosilicate glass averaging one-quarter inch in thickness. With the exception of heavy metal oxide glasses, such as lead glass, etc., borosilicate or pyrex has practically the same absorption characteristics as that of lime glass.

The Westinghouse manufacturers have adopted a *double-wall envelope* construction in their roentgen therapy tubes. It is claimed that the total thickness of the two envelopes combined does not exceed that of a single envelope of a competitive tube having the same rating; and, hence, the r-output is not affected. When such a tube is constructed for oil-immersion, both of its inner and outer envelopes are each of a thickness of one-tenth inch. The portal window of the outer shield is one-sixteenth of an inch in thickness, and the included oil between the outer envelope and the window is one-eighth of an inch. The total X-ray absorption of these three factors is equivalent to 0.2 to 0.3 mm of copper, of which the oil and the window contribute approximately 0.05 mm of copper. Because no electrical connection exists between the inner envelope and either one of the electrodes, the envelope is not subjected to the same electrical stresses prevalent in tubes of conventional design.

During operation of an X-ray tube it is not uncommon to observe a fairly pronounced *fluorescence.* The glow, which varies from apple-green to blue for pyrex, should not be mistaken as an indication of gas in the tube. If it is distributed only at the surface of the glass envelope, the phenomenon is then due to stray electrons and does not bear any significance. But, if a fluorescent discharge takes place in the space between the electrodes, seasoning the tube will usually remedy the cause. If the latter process does not improve the operation of the tube, gassiness of the tube is indicated.

Since fluorescence at the surface of the glass under bombardment by high velocity electrons may be accompanied by considerable heat, this latter factor markedly diminishes with air-cooled tubes. Hence, the oil-immersed principle renders it possible to design a tube with shorter anode arm and smaller bulb construction.

(*c*) *The Gas Pressure In A Hot-Cathode X-Ray Tube.*—In a hot-cathode type of X-ray tube it is of considerable importance that the gas pressure in the tube be maintained below that which will give rise to spontaneous ionization. It is only through eliminating the cause of the later factor that a complete control over the electron flow expressly by means of the temperature of the filament can be insured. Once the gas pressure reaches a value

sufficient to give a spontaneous or cumulative ionization the flow of electrons becomes uncontrollable, resulting in gaseous discharge between the electrodes. The effect further causes the liberation of additional gas, with consequent increase in stray electrons, and hence, heating the glass envelope. In some cases, failure of the tube may result.

So long the pressure at this critical value is not exceeded the tube current is mainly controllable by the filament temperature. The critical tube pressure at which spontaneous ionization due to residual molecules occurs is determined by the nature of the gas involved, by the applied potential, and by the design of the tube. Table VII* gives a list of gases with permissible tube pressures for proper operation of the tube at 85 Kv.P., and 30 M.A.

Table VII:—Maximum Allowable Gas Pressures In X-Ray Tubes.

Helium	5.0 – 10.0 microns
Hydrogen	4.0 – 8.0 microns
Nitrogen	0.5 – 1.0 micron
Water Vapor	0.2 – 0.5 micron
Mercury Vapor	0.01– 0.03 micron

The presence of such gases as Oxygen, Water Vapor, and Mercury Vapor, and in some cases even Nitrogen, due to their reacting with the hot filament, becomes particularly undesirable in electron type X-ray tubes. Therefore, special care is exercised in exhausting these tubes to as high a vacuum as possible, between 0.01 to 0.0075 micron, and even more so for high-tension sealed-off therapy tubes.

Aside from eliminating all foreign gases from a roentgen tube, the problem of maintaining the high vacuum by adequate choice of target material is of considerable significance. During operation of the tube, as the target temperature may rise to a value to cause the volatilization of the metal hence the rise in the vapor pressure, metals of high melting point (having low vapor pressures) are used for target material. Tungsten, due to its extremely low vapor pressure, has proven to be an excellent target material. At room temperatures, the vapor pressure of tungsten is so low that it can not be detected by any known means. But at 2700°C this pressure reaches a value of one micron; at 3000°C, it is approximately 1.5 microns, and the rate of volatization of tungsten is about 0.02 milligram per square centimeter per second,[1,2] a pressure of the same order of magnitude as maintained in usual types of gas-tubes; and at 4727°C (at boiling point of tungsten) the pressure reaches 760 mm. The temperature of the X-ray tube target seldom exceeds 3000°C. The stability of an X-ray tube, then, is only insured when its initial gas pressure is rendered so low as to allow a margin of safety in case gas is liberated during the operation of the tube.

(*d*) *Focal Spot Characteristics; Anode Design.*—In an X-ray tube, the electrical energy for the production of X-rays must necessarily pass through

*M. J. Gross and Z.J. Atlee, Progress in X-Ray Tube Manufacture, Radiology, Vol. XXI, page 363, Oct., 1933.

[1] C. Zwikker, Dissertation Amsterdam, 1926.

[2] A. Bouwers, Philips X-Ray Research and Development, 1923-1937, p. 1.

the focal spot. The magnitude of the permissible energy (rating of the tube) depends principally on the focus area, and, to a large extent, on the target material. Since, about 99% of the electrical energy passing through the focal spot is transformed into heat, the rating of a given X-ray tube is determined by the instantaneous heat tolerance and mechanical strength of the focus metal and by the high heat conductivity of the anode (anticathode) incorporating the focal spot. Copper has been selected as the anode material, and Tungsten as that of focus. The latter metal has the peculiar property of withstanding enormous mechanical stresses due to electron impact, and further possesses a high fusion point, low vapor pressure, fairly good heat conductivity, and, owing to its high atomic number, a favorable efficiency for the production of X-rays; whereas, copper has the inherent characteristics of high heat conductivity and relatively great mechanical strength.

The melting point of pure tungsten is 3370°C, while that of pure copper is about 1080°C. Copper has a thermal conductivity three times as high as tungsten. The combination, then, provides an efficient target having high quality X-ray emission properties together with excellent heat conductivity afforded by copper.

If the power applied to the tube exceeds that of its rated capacity, the temperature of both the tungsten focal spot and of the copper backing will rise abnormally. The maximum permissible temperature for the surface of the focus metal is 3000°C,[1] as beyond this temperature the metal volatilizes, thus causing instability of the tube. For favorable operations at maximum temperatures, the tungsten button must have a thickness consistent with the duration of the load, and must make a close thermal contact with the copper behind it. For a thickness of 2 mm tungsten target at a temperature of 3000°C, Bouwers[2] has shown that the temperature at the boundary surface between tungsten and copper is only 1050°C, as illustrated by the graph in Fig. 125.

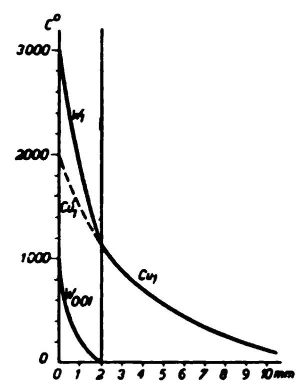


FIG. 125. GRAPH ILLUSTRATING THE TEMPERATURE DIFFERENCE BETWEEN THE TWO SURFACES OF TUNGSTEN TARGET WITH COPPER BACKING.

The curve W_1 - Cu_1, in Fig. 125, represents the temperature distribution at the target in a plane perpendicular to the anode face, and is determined on the consideration of 20,000 watts applied for one second per square centimeter of the tungsten target having a thickness of 2.0 mm. In this consideration, however, the difference of greater temperature gradient of tungsten than that of copper, and a small amount of heat conduction in a lateral direction of the focus are neglected, which factors entail only a negligible error.

Bouwers[3] has calculated the temperature rise for short-period loads on a stationary line-focus target, as in medical practice it is highly desirable

[1,2] A. Bouwers, Physica 10, 1930, p. 125.

[3] A. Bouwers, Zeitschr. F. Techn. Physik, 271, 1927, p. 8.

to reduce unsharpness in the radiograms of especially the moving viscera, which effect may arise from unnecessary long exposures. His calculations indicate that the increase of focus temperature is a direct function of the momentary value of the impressed energy. On this basis, the maximum specific rating (watts per sq. mm) of a tungsten focus of most favorable thickness 1.7 mm firmly adhering to copper behind it is found to be 250 watts per second per square millimeter of target surface.

In equation (105), Bouwers[1] presents a solution for surface temperature determination for exposures up to 0.04 second.

$$T=\frac{Q}{2k\sqrt{\pi}}\int_0^{4a^2t}\frac{\delta\tau}{\sqrt{\tau}}=\frac{2Qa}{k\sqrt{\pi}}\sqrt{t} \tag{105}$$

in which, T is the final temperature (degrees centigrade) of the target face, Q the energy per sq. cm in calories, a is equal to k/c, where k is the coefficient of thermal conductivity and c the thermal capacity per cubic centimeter for tungsten, and t is the exposure time in seconds.

From a radiographic standpoint, the size of the focal spot, the thickness, and its angular position with respect to the field of exposure are of primary importance. Considering a given arrangement and thickness of tungsten focus with copper backing, let us assume that the distribution of energy applied to the target is absolutely uniform over the entire focal area. Let us further assume that an energy, for instance, of 600 watts is applied for one second on a focal spot having an area of 4 square millimeters. Each square millimeter of the focus area will then receive 1/4th of the total energy, i.e., 150 watts. Increasing the focus area, for instance, to 8 square millimeters, and applying the same load as before, the energy received per sq. mm of the focus surface will diminish to 75 watts; and, reducing the focal spot, for instance, to 2 sq. mms, the impressed energy per square millimeter will increase to 300 watts, whereby each portion of the focal spot will be called upon to withstand the additional impact of the increased energy.

A 100-mil disc of tungsten target backed by a copper shank of cross-section 40 to 50 times that of the focal spot area will afford the application of 250 watts for one second to each square millimeter of the focus area.[2] It is also found that with a copper backing of a cross section approximately 10 times that of the focus, the permissible energy per square millimeter is only 125 watts prolonged for one second.

If the target is oil-cooled, and the distance between the back of the target and the oil does not exceed 6 mm, the focus can withstand a continuous load somewhat above 200 watts per sq. mm. Westinghouse engineers have developed deep therapy tubes in which the target is cooled by oil circulating at the rate of 13 quarts per minute under full load. It is claimed that the copper temperature behind the target under full load does

[1](A. Bouwers, Zeitschr. f. Techn. Physik, 271, 1927, p. 8.
(A. Bouwers, Physica, 10, 1930, p. 125.
[2]M. J. Gross and Z. J. Atlee, Radiology, Vol. XXI, page 365, Oct., 1933.

not exceed 190°C, while the temperature at the cooler is approximately 25°C.

From the foregoing, it follows then that the size of the focal spot determines the maximum short time energy which can be safely applied to the X-ray tube. It has been found that the maximum permissible energy that can be safely applied to the focus of a stationary copper anode with a tungsten target is approximately 200 watts per second per square millimeter of the focal area.

It is thus evident that if the rated energy of a tube is lowered below the normal permissible load, the energy distribution per unit area of the focus will be lowered, with a consequent diminution in the X-ray density. This will render the focal spot an unnecessarily large area; and, as a result, loss of definition in the radiographic detail will incur. Conversely, if the focal spot is impressed with an energy above that which its physical limitations will permit, then the life of the tube will be shortened. Tubes with continuously moving focal spot are constructed, which "permit of short loads seven to eight times those permissible for a stationary anode."* By use of this type of X-ray tube, the radiographic detail can be markedly improved without sacrifice in speed. In a later section, however, these tubes will be discussed in particular respects.

The focal spot size of an X-ray tube does not change in service if used at its normal rating. But, if the tube is operated at an insufficient voltage, such as at 35 Kv.P. or below, the focal area increases to an appreciable extent. This change, however, is not affected by the magnitude of the milliamperage through the tube. Instability of the focal spot size may also occur from gassiness of the X-ray tube, which, then, should not be expected to give good radiographic results.

Generally the focus metal has a thickness varying from 1 mm to 4.5 mms, depending on the type of the X-ray tube. Owing to its high atomic number, and high melting point, tungsten is invariably used in all focus metals of X-ray tubes for medical use — the former characteristic producing high penetration quality X-rays, and the latter rendering relatively long tube

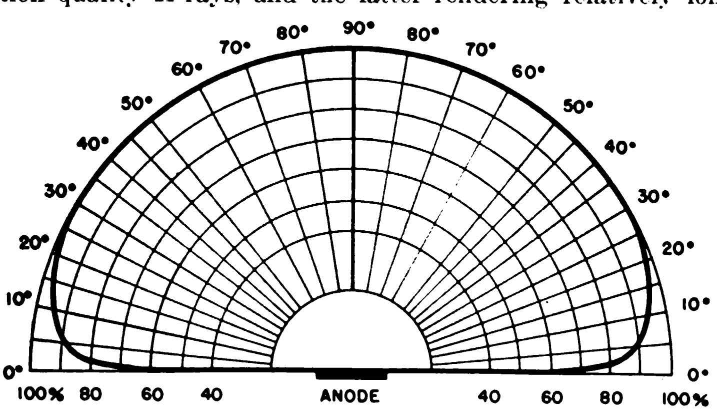


FIG. 126. DISTRIBUTION OF X-RAY INTENSITY AS A FUNCTION OF THE ANGLE OF EMERGENCE.

*A. Bouwers, Kongressheft Fortschr. a. d. Geb. d. Rontgenstrahlen, 20, 1929, p. 103.

life, which averages, for good quality tubes, approximately 2000 operating hours.

It is thus obvious that the load-carrying capacity of an X-ray tube is determined by the size of its focal spot, since almost the entire impressed energy passes through this area. The larger the focal spot the greater load can be applied to the tube.

The shape and the angle of the focus play an important part in the load capacity consideration of the tube. For instance, using a line-focus target of 20 degree angle, substantially the same intensity of radiation as from that at 45 degrees is produced, as illustrated in Fig. 126.

It is further observed that a line-focus having the same target angle and the same optical effect as that of a round-focus can withstand loads twice as high as that withstood by the round-focus. Thus, exposures as short as 50% of that with a round focus can be obtained with this type of focus.

As will be noted from the curve in Fig. 126, the intensity of X-rays emerging from the target is dependent on the angle between the focal surface and the X-ray beam. X-rays whose emergent angle is larger will give rise to a greater intensity than that of those whose emergent angle does not exceed a few degrees with respect to the target surface. With zero degree angle, for example, it is not possible to obtain the most useful X-rays, whereas with an emergent angle of only 5 degrees, the radiation density of X-rays is increased to 85% that at the most favorable angle, which is obtained at 17 to 20 degrees.

The diagram of a line-focus is given in Fig. 127. It will be noted that with a line-focus at 20-degree angle the projected focal area is approximately 1/3rd that of the actual focus area. The X-ray intensity at the projected focus is then three times greater than that of the radiation normally emergent from the target face.

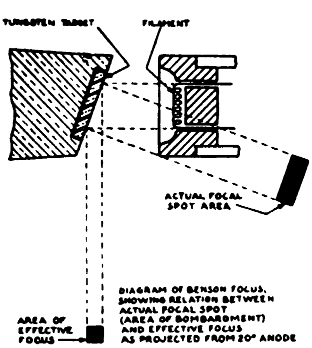


FIG. 127. THE DIAGRAM OF THE LINE-FOCUS (BENSON FOCUS).

Owing to the shortened projection of the focus with a 20-degree target angle, an increase in radiographic detail is realized without sacrifice in speed. But, radiographs made at a short anode-film distance, for instance, at 25″, will not receive a uniform radiation intensity, as, for example, emergent rays making an angle less than 5 degrees with the target surface will possess less density, and hence will produce blurring (or at least, will diminish sharpness of detail) at this end of the film. This fading off is known as the *"heel-effect,"* and it becomes annoying at relatively short target-film distances. Because of the higher load capacity of a line-focus tube compared with that of the round-focus construction, the anode-film distance may be considerably increased without sacrifice in exposure time but with material improvement in radiographic detail. With a target-film distance of 30 inches or over, then the *"heel-effect"* entirely vanishes.

On the other hand, it will be noted that with a given line-focus tube the maximum allowable film dimension is limited by the angle of the target face — the smaller the angle to a plane normal to the film the area that can be covered by the radiation is markedly reduced for a fixed target-film distance. A 14″ x 17″ film, which is generally used for radiographs of the chest, kidney, abdomen, lumbar spine, pelvis, etc., therefore, can not be entirely covered with uniform intensity radiation without increasing the target angle at a given distance, which, for a film of smaller dimensions, may be the optimum position. Since an increase in focus angle (to use, e.g., a 45° angle) will not be advisable in view of the resulting sacrifice in detail, a more preferable recourse is to increase the tube-part distance and the impressed power, a considerable increase in which is permissible with line-focus tubes, and more particularly, where these tubes are of rotating-anode type.

With stationary-anode line-focus tubes, which are in more general use at present, a more uniform distribution of radiation intensity over a large field may be obtained by tilting the tube (about 15 to 20 degrees) so that the plane of its target face makes a smaller angle with that of the film surface. This procedure, however, will be found, sometimes, to be inconvenient, or even impracticable, from the standpoint of proper tube alignment with the patient. Again, the importance of a maximum focus-film distance together with the highest permissible load consistent with the tube capacity and the given radiographic technic can not be over-emphasized, provided the latter factor does not call for a distance shorter than 25 inches. Where a target-film distance shorter than 25 inches is required, the realization of maximum possibilities will be met with a right-angle tube, such as RA-2 Coolidge tube, discussed in a previous section.

(*e*) *Cathode Design.*—The focusing of the stream of cathodic electrons accelerated in the direction of the electric field is accomplished mainly by the cathode structure and by the inter-electrode spacing. The effect is further dependent upon the size, shape, and position of the filament in respect with the focusing-cup and its dimensions. The problem of securing a predetermined focal area on the target is one of accurate controlling of the electrostatic action of the cathode shield surrounding the filament. The heat distribution of focal spot energy is obtained when the focusing cup and the focal spot are of the same dimensions. The focal spot dimension, however, may be increased or decreased by varying the size and the shape of the focusing-cup structure, or by varying the position of the filament in this cup. The size of the focal spot can also be determined by electrically insulating the filament from the focusing shield and maintaining it at slightly lower negative potential than the latter. The Müller *autofocus* tubes are characteristic of this design.

The metals generally used as cathode material are Tungsten, Nickel, Steel, and Molybdenum. The last is the one more commonly used for electron-focusing shield in usual diagnostic tubes. Careful design, assembly, and exhaust are of major importance in the production of an X-ray tube that will stand the severe requirements in obtaining satisfactory tube performance. Again, the desirability of having an adequately designed focusing-shield and the proper spacing between the cathode and the anode can not be too greatly emphasized.

The spacing between the electrodes is determined by the maximum rated kilovoltage at which the tube can operate, by the shapes of the electrodes, and by the surface irregularities.[1] The permissible variation in the spacing is plus or minus 0.5 mm. Within this limit, no appreciable effect on the size of the focal spot or on its energy distribution is observed, both of which factors are dependent upon the cathode design.[2] It is determined through experimental observations that when the filament is placed parallel to the target face, the spacing between the electrodes must be increased, otherwise the tube will operate erratically, and surging may result. Hence, by positioning the target at some angle with respect to the filament, the spacing between the anode and the cathode may be made smaller, with a consequent diminution in tube impedance.

Tubes having double-focus (two separate filaments of different sizes) have been available for many years. The cathode of this type of tube has two focusing-cups — one, incorporating a large filament (corresponding to a broad-focus tube) for high millamperage exposures, and the other, a smaller filament (corresponding to a fine-focus tube) for light duty or fluoroscopic work. With a selector switch mounted at the cathode end of the tube, either one of the filaments can be readily selected by rotating the switch to the desired focus size. Because of a protective resistance arranged in series with the filament for the small focal spot, the possibility of accidental overload is eliminated. The target of the tube, accordingly, consists of two corresponding focal spots arranged side by side.

Two such double-focus tubes are offered by General Electric Company. One is constructed with the same foci of both the XP-1 (1.5 mm focus) and XP-4 (3.8 mm focus) tubes, and the other is a combination of XP-1 and XP-5 (5.2 mm focus). Both types are furnished with either an air-cooled, or a water-cooled radiator. The ratings of the individual foci of the double-focus tubes are same as given for the separate single-focus models incorporating the respective foci. A rotating-anode diagnostic tube with double-focus, developed by General Electric engineers, has been available since 1936.

Two types of double-focus heavy anode X-ray tubes are offered by Philips Metalix. The 2/6 KW is a combination of 2-KW 1.7 mm focus with a larger 6-KW 3.1 mm focus; and, 2/10 KW incorporates the same 1.7 mm focus of the 2-KW tube with 4.1 mm focus of the 10-KW. It is claimed that fine bone detail in films of extremities and skull is obtained with the small focal spot, while with the larger foci technics varying from 30 M.A. to 100 M.A. with 6-KW focus, and from 100 M.A. to 250 M.A. with 10-KW focus for chest and visceral radiographs, are made possible with these tubes.

(*f*) *X-Ray Tube Seals.*—In an X-ray tube, there are two types of seals—*metal-to-metal,* and *metal-to-glass.* The metal-to-metal sealing centers around the electric-welding of the parts constituting each electrode; and, the metal-to-glass seals involve the vacuum-tight assembly of the electrodes to the glass envelope.

[1] M. J. Gross, Characteristics of Roentgen-Ray Equipment, The Amer. J. of Roentg. and Radium Therapy. Vol. 26, No. 4, October, 1936.

[2] Westinghouse X-Ray Tube Manual, 1935 Issue.

The most important of the metal-to-metal seals is the welding of the tungsten target into the copper anode. A process developed by Westinghouse X-ray Corporation makes it possible to completely unite the tungsten with the copper, producing an intimate junction of the two metals. The scheme consists of heating tungsten button with copper in a neutral atmosphere at about 1200°C, at which temperature the copper melts and flows around the tungsten, producing an intimate bond with the latter metal. This done, the copper-impregnated tungsten button is placed on the target face of the copper and the two metals are again heated and maintained at 1200°C for a sufficient time to insure thorough fusion of the copper anode to the copper previously cast around the tungsten. The assembly is then gradually cooled down with uniform heat according to a definite schedule, and finished on extremely close limits on engine lathe.

In sealing the anode, and the cathode, to the glass, a thin layer of cuprous oxide (either previously applied or formed during sealing) at the junction between the two surfaces effects a very efficient vacuum-tight union. The re-entrant design of each end of the glass envelope further insures a tight sealing of the metal to the glass.

Chromium-Nickel Steel, or Chromium-Iron alloy, such as used for the discharge chamber in Philips Metalix tubes, possess properties which enable the direct sealing of the metal to the glass. During the heating of the two joints, a layer of metal oxide is produced at the junction between the glass and the metal. The oxide dissolves in both the glass and in the metal, thus producing an intimate union of the two surfaces.

There are at least two metal-to-glass seals on every X-ray tube — one, at the anode end, and the other, at the cathode end of the envelope. In the case of Metalix tubes, however, three additional seals are necessitated. Of these, two are made at each end of the central metal discharge cylinder, and one at the glass window incorporated into the central portion of the cylinder across the target end of the anode.

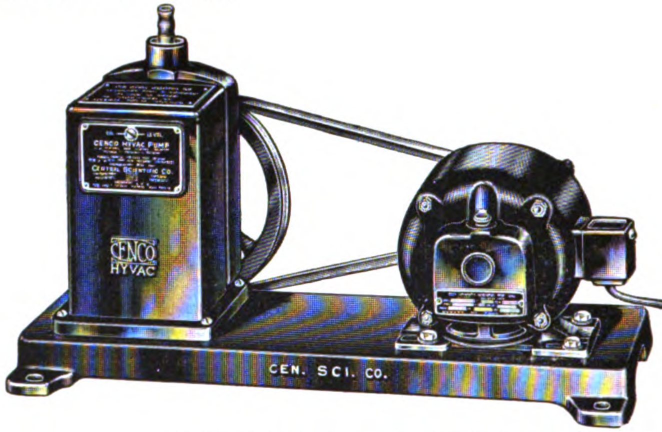
(g) *Processing Of The X-Ray Tubes;*[1] *Final Tests.*[2]—Previous to the assembly of the X-ray tube all component parts are thoroughly cleaned with distilled alcohol and distilled water to remove all impurities normally retained at their surfaces. Further removal of any absorbed, or adsorbed, gas forming a surface film on the metal parts is effected by treating them in a vacuum chamber with short-wave (wave-length from 100 to 1000 meters) radiofrequency energy, which heats all metal parts to a high temperature. The tube, then, is assembled and connected to a vacuum pump for exhaust.

During evacuation, the tube is enclosed in a vacuum furnace for baking the glass at from 400 to 500 degrees centigrade. Since hard glass tubes can withstand higher temperatures than those with soft glass envelopes, the former can be baked out at 500°C so that a more thorough degassing of the glass is realized. All metal parts, however, that cannot be adequately degassed by any other means are treated with high frequency heating transferred to them by induction from a coil placed around the glass en-

1,2. M. J. Gross and Atlee, J., of G. E. Co., Prog. in Mfr. of X-Ray Tubes, Radiology, Vol. XXI, p. 365, Oct. 1933.

Westinghouse X-ray Tube Manual, 1935 Issue.

velope, as shown in Fig. 129. In the case of tubes to be operated at extremely high tension loads (tensions above 200 Kv.P.), the process of degassing is further extended.



(COURTESY CENTRAL SCIENTIFIC COMPANY)
FIG. 128. A VACUUM PUMP WITH AN ELECTRIC MOTOR.

As the pumping operation proceeds, the cathode filament is heated in excess of its maximum ratings, and a potential is applied by gradually increasing its magnitude to a maximum permissible value. The tube, then,

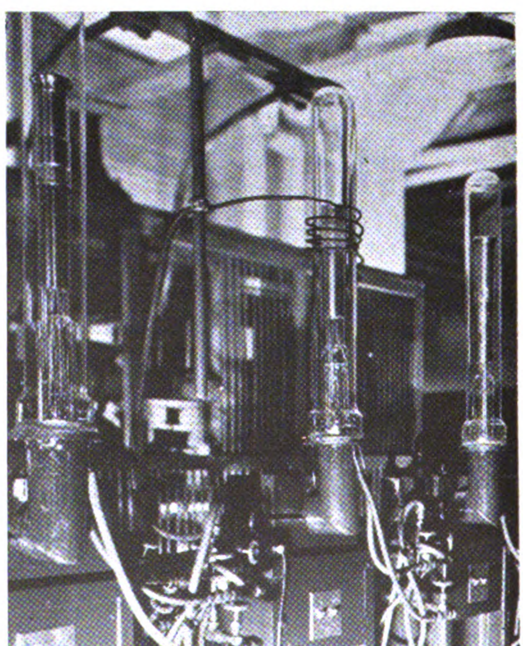


FIG. 129. DEGASSING THE METAL PARTS BY RADIO-FREQUENCY HEATING IN A VACUUM.

is intermittently operated (at high milliamperage and short-time bombardment for radiographic tube, and at continuous low milliamperage for therapy tubes) until a fair measure of stability is reached. A vacuum-measuring device, known as the ionization gauge, indicates, in a practical and accurate manner, the final pressure inside the tube before it is permanently disconnected from the exhaust pump.

As mentioned before, all parts of the tube are heated to temperatures far above that in actual operation, and the resulting increase in gas pressure is noted by means of the ionization gauge. If the test is satisfactory, the tube is sealed off the pump; if not, the exhaust process is continued until no further gas is evolved and the tube operation becomes stable.

Subsequent to the processing and to the sealing of the bases to each end of the tube, various operative tests are applied to the tube, according to its type—continuous operation at voltages in excess of permissible ratings to therapy tubes and fluoroscopic tubes, and intermittent to radiographic units. The cathode is operated overloaded for 30 minutes, which period insures a thoroughly degassed cathode structure; and, the milliamperage drop test, which is prolonged at least for 24 hours, further insures against leaks and the presence of deleterious gases , especially water-vapor, Oxygen, Mercury, Oils or Greases, which poison the electron emission from the tungsten filament, causing an appreciable variation in the tube milliamperage.

Before an X-ray tube is considered to be ready for distribution, two focal spot pin-hole pictures are made to be definitely assured that the correct focal spot size and uniform energy distribution are attained during manufacture and assembly of the tube. Furthermore, the tubes are kept in stock for at least two weeks and then re-tested for leaks before shipment.

QUESTIONS ON CHAPTER XIII

1. (a) What are the chief objects concerned in the development of modern X-ray tubes?
   (b) On what factors is the penetration quality of X-rays from an ionic tube dependent? Are ionic X-ray tubes self-rectifying? Why?
   (c) Can the penetration quality of X-rays from an ionic tube be varied independently of the intensity of the radiation? Explain, why?
2. (a) How does a hot-cathode X-ray tube compare with an ionic tube as regards to electron emission, variability of the penetration quality and the intensity of X-rays, and stability of performance?
   (b) What distinct advantages are held by the ionic tube over that of an electron tube?
   (c) Discuss why a universal X-ray tube is not operated self-rectified. Give the general characteristics of a universal X-ray tube.
   (d) Describe the structural features of a diagnostic X-ray tube.
3. (a) What properties of an electron X-ray tube render it self-rectifying?
   (b) What special significance is held by oil-immersion principles as applied to roentgen tubes?
   (c) Discuss the essential features of some of the roentgen therapy tubes and their applications.

(d) What difficulties must be overcome in the construction of a high-voltage therapy tube?

4. (a) How is the preclusion of the stray and secondary electrons from the glass envelope of an X-ray tube realized? Give two methods of attaining this end.
   (b) Describe fully a Philips Metalix research tube.
   (c) What significant place is held by X-ray spectroscopy in the investigation of different materials of commerce?
   (d) When X-ray tubes with high load capacities were made possible, what new problems presented themselves?

5. (a) Discuss fully, how the physical dimensions of an X-ray tube are determined during manufacture?
   (b) Give the different types of X-ray tube envelopes now in general use, pointing out their practical advantages.
   (c) Why is it necessary to maintain the gas pressure in an electron type X-ray tube below that which will produce spontaneous ionization? What effect has the target material on the tube pressure?

6. (a) How does the focal area determine the maximum short time energy which can safely be applied to the X-ray tube?
   (b) Discuss the dependence of the permissible load capacity of a roentgen tube on the focus area and target material.
   (c) What inherent thermal characteristics of copper and tungsten render the combination an efficient target structure?

7. (a) What important part does the target angle play as regards the load-carrying capacity of the focus, the X-ray intensity, and the area of the film covered by the radiation?
   (b) Discuss cathode structure as regards the emission of electrons.
   (c) Discuss fully the sealing, processing, and exhausting of an X-ray tube.
   (d) What tests are performed on the X-ray tube previous to its release from the factory?

CHAPTER XIV

X-RAY TUBES
(Cont'd)

1. Secondary Electrons In An X-Ray Tube.—It has already been observed that electrons liberated from the cathode of an X-ray tube are projected at extremely high speeds toward the anode when a potential difference is maintained between the two electrodes. Upon impinging on the tungsten target, most of the electrons (about 99%) penetrate into the interior of the metal and transfer the greater portion of their kinetic energy to the neighboring atoms, resulting in the liberation of heat. In the event the energy of the primary electron is expended in ejecting an electron from the target atom that the latter is raised to a state of excitation, or, of ionization, a characteristic radiation is emitted as a result of the atom returning to its normal state. A small percentage (less than 1%) of the primary electrons, however, will be arrested instantaneously, upon collision, by the nucleus of the target atom, in which case, the kinetic energy $\frac{1}{2}mv^2$ of the electron will be converted into radiation energy hf. This is the phenomenon that gives rise to a continuous spectrum from the X-ray tube. The effective depth at which this takes place (depending on the voltage and on the target material) in a tungsten target is of the order of 0.5 to 1.0 micron (about 2500 to 4000 atoms deep) from the surface.

There is, however, still another category of electrons, which introduce complications in tube performance. They are those electrons that after impinging upon the target bounce off from it with decreased velocities to be attracted to the anode shank, or, to the glass envelope. Among these are included electrons which have been removed by the primary electrons and are caused to diffuse back to the surface of the target metal. The effect, which may be termed, for convenience, *"the scattering of electrons,"* principally forms the subject of our present discussion.

Whenever some of the rapidly-moving primary electrons upon impinging on the target rebound to the glass envelope of the X-ray tube, they induce to the inner surface of the glass a negative electrostatic charge in respect to the outer surface, producing a difference of potential between the two surfaces. The kinetic energy $\frac{1}{2}mv^2$ of each electron may appear, in the glass, as heat energy $Ve/300$. Consequently, a small amount of gas may be liberated from the glass walls, and, when ionized, some of the ions may pass from the electrodes, through the glass, to the air, and back to the respective electrodes, producing electrolysis of the heated glass, and possibly, a destructive discharge. Should further ionization of the gaseous electrolytic products occur, the current through the tube may rise to an abnormal value, thus increasing the intensity and lowering the quality (hardness) of the X-ray radiation.

Some of the stray (secondary) electrons from the target surface may become attracted back to the anode shank and hit it all over its surface

with decreased velocities, giving rise to secondary X-ray radiations (also known as stem radiations). Or, they may produce tertiary electrons, which, in turn, may give rise to tertiary X-rays, and photo-electrons. This results in an impairment of the uniformity of the useful X-ray beam reaching the film, and hence, of the radiographic quality.

As has been previously pointed out, these difficulties are surmounted by the provision, around the anode, of a cylindrical shield which intercepts the escaping secondary electrons from the target face. One design offered by General Electric engineers is to completely surround the anode with a hollow cylinder of copper provided with two apertures—one, for permitting the passage of the cathode stream to the anode, and the other, for that of the primary X-rays from the target. A schematic diagram of the sectional view of the tube structure is shown in Fig. 130.

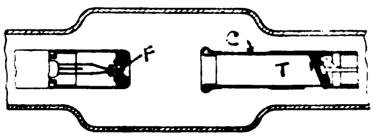


FIG. 130. CATHODE-ANODE STRUCTURE OF GENERAL ELECTRIC XPT-4 TUBE.

The electrons projecting from the filament F pass through the cylinder C to the tungsten target T, where, some of them produce heat, others produce X-rays, and still others rebound with lower velocities. Because of the relatively small heights of the trajectories of the stray electrons compared to the length of the cylinder, they are unable to get out of the latter, but are attracted back to it and carried away through the circuit. The arrangement leaves the envelope free from the additional electrostatic stresses otherwise present due to secondary electrons.

Bouwers and Tuuk describe, in Physica 12, 1932, page 274, various designs for cathode and anode structures, pointing out that no screening device for secondary electrons is necessary if sufficiently large area is given the anode face surrounding the focal spot. It is shown that the fastest secondary electron leaves the target surface at 45° angle, with a maximum range of twice the distance between the two electrodes. Thus, the minimum interelectrode space must not fall below twice the height of the electron trajectory, which is 1/4th its entire range.

The authors further describe an example embodying the *principle of restricted range* in which electrodes assume spherical configurations. Fig.

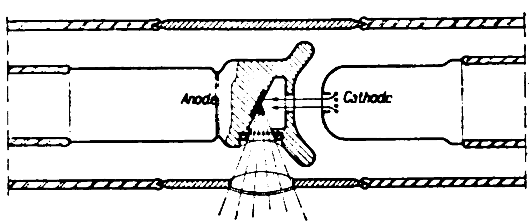


FIG. 131. APPLICATION OF THE PRINCIPLE OF RESTRICTED RANGE.

131 shows an application of the elecrron-screening shield for strey electrons. It is claimed that "owing to the gradual curvature of the cathode," the

tendency for a cold discharge as likely to occur in high tension tubes is considerably reduced.

2. Reasons For A Cooling System At The Anode*.—The electrical energy applied to the X-ray tube for the production of X-rays must necessarily pass through the focal spot. Nearly all of this energy is transformed into heat, which is conducted through the copper anode shank to the exterior of the tube. Only a small proportion, 0.025 to 0.25 percent, of the energy received at the target is effective in producing X-ray radiation. Recent reports, however, disclose that the development of an experimental X-ray tube, using powerful electromagnets, makes it possible to draw from the tube between four to six times more X-ray radiation than that given by an ordinary diagnostic tube.

It has already been stated that the permissible load of a diagnostic X-ray tube is a direct function of the focus area, and that the specific load capacity (watts per square millimeter of focus area) for a stationary-anode tube is 200 watts per square millimeter of tungsten focus backed by copper anode. An impressed power of 50 kilovolts and 40 milliamperes is same as that of 80 kilovolts and 25 milliamperes prolonged for the same exposure time. With a focal spot area of 32 square millimeters, then, the maximum load that can safely be applied to the tube is 6.4 kilowatts, which is known as the rating of the tube.

The temperature of the target is determined by the size of the focus metal, by the specific heat and thermal conductivity of both the tungsten focus and its copper backing, and by the duration of the applied energy to the X-ray tube. The greater the magnitude of the applied power, the higher the temperature of the target will rise. With a given load on the tube, the rise in temperature of the anode depends upon the duration of the exposure time. Thus, unless a provision is made to conduct the heat away, the target face may become so hot as to volatilize, or even crack, with the result that the X-ray output of the tube will be considerably reduced, and, continued exposure may even cause the destruction of the tube.

The rise in temperature of the target may be quantitatively calculated by a consideration of the following example: Let us assume that a power of 1.2 kilowatts (60 kilovolts and 20 milliamperes) is applied for 0.6 second to a tungsten target initially at 30°C. If all this power is transformed into heat at the focus, the energy in calories will be given as

$$E_c = .24IVt \text{ calories} \tag{106}$$

where, $I = 0.02$ ampere.
$V = 60{,}000$ volts.
$t = 0.6$ second.

Hence,

$$E_c = .24 \times .02 \times 60{,}000 \times .6$$

$$= 172.8 \text{ calories}$$

*Also see, A. Bouwers, Philips X-Ray Research & Development, 1923-1937, pp. 1, 125. Westinghouse X-Ray Tube Manual, 1935 Issue, pp. 18 & 41.

of which energy 40% (coefficient of thermal conductivity of tungsten = 0.4) is conducted away to the copper anode shank. Hence, the effective calories remaining in the tungsten will be 60% of 172.8 calories, or

$$E_c = 172.8 \times .60 = 103.68 \text{ calories.}$$

Let us further assume that the tungsten target which receives this energy is 2 mm wide, 16 mm long, and 3.2 mm thick. Its volume, then, will be 0.1024 cubic centimeters. Since the density of tungsten is 19.3 grams per Cc, the mass of 0.1024 Cc of the metal will be 19.3 x 0.1024 = 1.9763 grams. Taking the specific heat* H of tungsten as 0.036 calories per gram, the rise in temperature T by the application of $.24IVt$ calories may be represented by equating the two quantities together as

$$MHT = .24IVt \tag{107}$$

from which equation, solving for T, we obtain

$$T = \frac{.24IVt}{MH} \tag{108}$$

where T is given in degrees centigrade, and M is the mass of the tungsten focus in grams.

Assigning the numerical values of the individual quantities in the right-hand side of the equation and taking 60 per cent of the energy, we obtain

$$T = \frac{.24 \times .02 \times 60{,}000\ .6 \times .6}{1.9763 \times .036}$$

$$= 1457.2°C.$$

But, initially a temperature of 30°C was assumed for tungsten. Hence, the final temperature of the target will be

$$1457.2 + 30 = 1487.2°\ C$$

which temperature is assumed to be uniformly distributed in the target metal, which condition can not apply in practice, since the surface temperature of the target is always higher than that of the portion next to copper, which fuses at temperatures above 1080° C. But, by referring to the curve in Fig. 125, it will be noted that though the temperature of the surface is well above that attained in the above consideration, the temperature of the copper immediately behind the tungsten button is far below the fusion point of copper. Thus, the power assumed in the above example is quite permissible. The practical significance of our discussion, however, is illustrative of the production of a tremendous heat by the kinetic energy of the electrons of impact.

*Specific heat is defined as the number of calories required to raise the temperature of one gram of a substance one degree centigrade. The specific heat of water is taken as 1.

Owing to the above factors arising from thermal considerations of tube loads, each X-ray tube is provided with adequate cooling system. Some tubes are cooled by metallic radiators, while others are cooled by water constantly circulating behind the tungsten target backed by a few millimeters of copper. Still others are cooled by means of an insulating liquid (oil), which either completely surrounds the tube or circulates inside the anode by means of a special pumping unit. Very few air-cooled type of X-ray tubes are used in clinical radiographic work.

The advantage of oil-cooling as against water-cooling is that the former, providing an efficient means of insulation between the tube bushing and the tube housing, permits the grounding of the tube without additional insulations. On the other hand, the thermal conductivity and the specific heat of oil are about 1/8 of those of water—hence the necessity of a forced cooling. The viscosity of oil is directly influenced by temperature, and at very high temperatures the oil decomposes, forming carbon, thus affecting the stability characteristics of the oil as a cooling medium. However, through adequate choice of oil as a cooling medium together with properly designed channels immediately behind the target for the circulation of the liquid, acquisition of favorable results is made possible.

With a thin film of oil travelling at maximum speed and uniformly covering the back of the target of Westinghouse tubes, it is claimed that adequate cooling of the target is realized.

Oil-cooled tubes are also available through other manufacturers such as General Electric X-Ray Corporation, Philips Metalix, etc. The G.E. Model CDX Coolidge tube employs the principle of tube operation in oil. Together with its high voltage transformer, the tube is completely immersed in oil, and hermetically sealed and grounded in a single container. It combines 100% electrical safety with absolute X-ray protection.

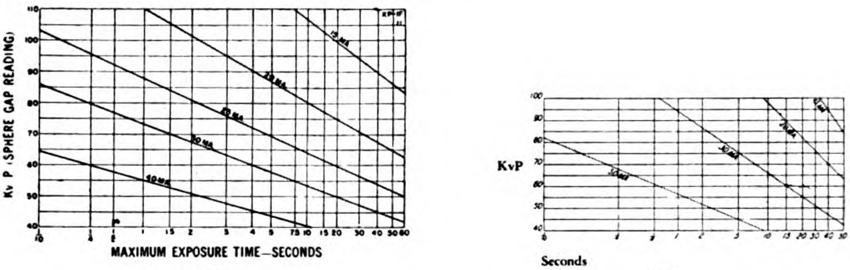
Bouwers* describes a simple cooling system employing simultaneously the advantages of the thermal capacity of the cooling medium and its thermal radiation, and the dissipation of heat from this medium into the air by convection. The cooling element consists of a demountable spherical block of copper having a large thermal capacity. Owing to its large volume, the inclusion of the element renders the tube high ratings. A more recent modification of this cooling device is a continuation of the anode stem as a massive copper radiator with blackened Aluminum surface. Tubes furnished with this type of cooling element possess the advantage of water-cooled tubes having the same respective focal spot sizes. All metalix HA (Heavy Anode) tubes have the provision of this type of anode cooling.

It is further pointed out that with HA Metalix tubes accidental overheating, as entailed in a tube with water-reservoir due to its limitations of operative positions, boiling of the water, etc., is eliminated. The tube, aside from offering a complete X-ray protection, is adaptable for radiographic loads permitted by a water-cooled tube. For continuous fluoroscopic work the tube meets with favorable results.

The charts in Fig. 132 show the comparative maximum energy ratings of General Electric XP 1.5 mm focus tube and Metalix HA 1.7 mm focus

*Fortschr. a. d. Geb. d. Rontgenstr., 46, 1932, p. 718.

tube, both operated on full-wave rectified apparatus. The frequency with which the respective tubes can be loaded with a given applied energy are determined from the respective curves.



(1) (2)
FIG. 132. COMPARATIVE MAXIMUM ENERGY RATING CHARTS, (1) OF COOLIDGE XP-1 TUBE, (2) METALIX HA-2KW TUBE.

In making a series of radiographic exposures, it is not only important to know the maximum energy that can be safely used on individual exposures but also the frequency with which they can be repeated. To determine the minimum time interval necessary to cool the tube before the next exposure can be made, cooling curves have been carefully calculated for each particular type of tube by its manufacturer. These curves, which are usually furnished to the practitioner on delivery of the tube, show the rate of heat dissipation from the anode with various initial values of heat storage, which is expressed in arbitrary *heat units,* the product of *Kv.P.* x *M.A.* x *Seconds.*

Fig. 133 gives the cooling curves which apply to all Coolidge diagnostic tubes of the XP series, and Fig. 134 shows the cooling curves for Krom-iron or Metalix radiographic tubes. With either Coolidge or Metalix tubes

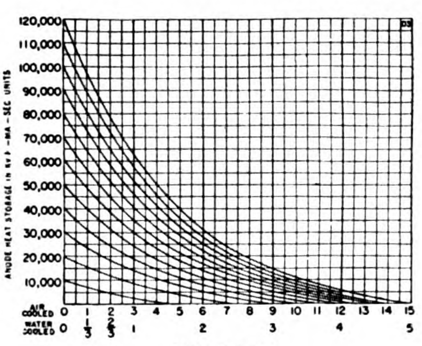


FIG. 133. COOLING CURVES APPLYING TO XP SERIES COOLIDGE TUBES.

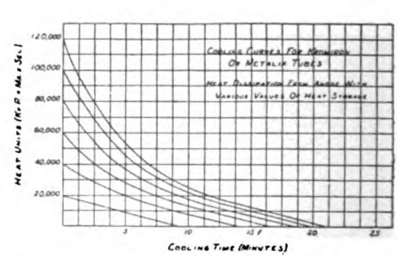


FIG. 134. COOLING CURVES APPLYING TO METALIX AND CHROME-IRON TUBES.

of respective series referred to under respective cooling charts, an exposure can be made when the total heat content of the anode from the previous exposure plus the heat involved in the exposure to be made does not exceed 120,000 heat units. For instance, with a cold anode, in making a series of

10 exposures at 60 Kv.P., 75 M.A., for 2 seconds each, the heat accumulated in the anode will be 10 (60 x 75 x 2) = 90,000 heat units. Since the heat involved is less than 120,000 units, these exposures can be conducted, if necessary, one after the other. If another series of 5 exposures, at 70 Kv.P., 100 M.A., for 1.2 seconds each, are to follow, a cooling time interval should be allowed, as the additional heat involved in the latter exposures will amount to 42,000 heat units. This will raise the heat content of the anode to 90,000 + 42,000 = 132,000 units, which is 12,000 heat units in excess of the limit of 120,000 heat units. If the 90,000 heat unit curve is followed on the Coolidge XP series chart, it will be noted that with air-cooled tubes approximately 40 seconds are required to dissipate the excess 12,000 units, while with a water-cooled tube this interval is only about 12 seconds, which time is astonishingly short.

In using a Coolidge XP tube, it is recommended, however, that a minimum of five seconds be allowed between rating chart exposures, excepting for stereoscopic work. This curves further indicate that cooling periods for water-cooled tubes are just 1/3 those for the corresponding air-cooled intervals. Thus, it will be obvious that while the rating charts apply in either case, a greater number of exposures can be conducted with water-cooled tubes in a given time.

3. Rotating-Anode X-Ray Tube.—One of the greatest advances toward perfection in diagnostic tubes is revealed with the emanation of the "Rotalix" X-ray tube, in 1929, from Philips Metalix Laboratories. The tube has a rotating anode, which, owing to its exposing to the electrons of impact a constantly changing focus area, offers the advantage of permitting the use of a higher specific load, thus producing a fundamental improvement in the radiographic quality. The rotating-anode principle permits the application of loads seven to eight times those permissible for stationary anode.*

The idea of incorporating a revolving area of electron impact in an X-ray tube dates back to 1898, when, J. L. Breton describes in his book, "Les Rayons Cathodiques et Rayons X", an X-ray tube which rotates during radiographic exposures "in a manner to constantly change the point of X-ray emission so as not to allow sufficient time for its heating to a point dangerously high."

In Proc. Roy. Soc. A., 117, 1927, page 30, A. Müller discusses his calculations for the rise in temperature of a stationary anode during radiography with long exposures, and subsequent to this his experiments with water-cooled rotating target are well identified with the history of the evolution of the "Rotalix" tube.

The Rotalix Tube, shown in section in Fig. 135, comprises a conical tungsten target W backed by a massive copper anode A, which is mounted

*A. Bouwers, Kongressheft Fortschr. a. d. Geb. d. Rontgenstrahlen 20, 1929, page 103.

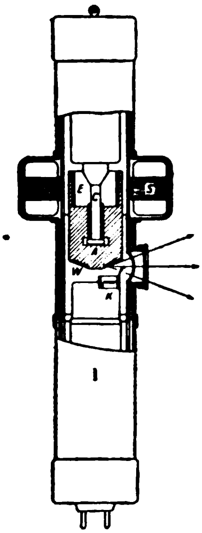
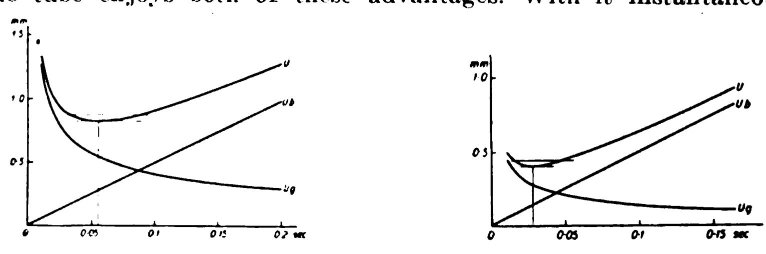


FIG. 135. SECTIONAL VIEW OF ROTALIX TUBE.

on the spindle C with self-lubricating bearings. The anode is provided with a cylindrical extension to form the rotor of an A.C. induction motor constituted by the latter in conjunction with a stator winding around the tube. An iron cylinder is snugly fitted inside the rotor to increase the number of lines of force threading the copper. S is the laminated iron core of the stator winding energized by three-phase current. When the tension is switched on, the rotating magnetic field of the stator winding produces eddy currents in the copper body, causing the anode to rotate on its spindle. Since the energizing current for the rotation of the anode is taken out from the circuit in the primary side of the X-ray transformer, the anode attains its full speed long before the X-ray exposure switch is closed. This eliminates the risks of making an exposure before the anode is rotating at full speed.

It will be noted that the cathode filament K is slightly off-centered in the direction of the tube window, allowing the cathode stream to fall on a trapezium-shaped focus area F. This latter shape of the focus is due to the increasing radius of the tungsten cone. The focus-track has a radius of 2.5 cms., and the breadth of the focus varies from 1.2 mm to 2 mm. The speed of rotation of the anode ranges from 20 revolutions (with older type tubes) to 40 revolutions per second, covering respectively a displacement of about sixty to hundred-twenty times the focus breadth. The adoption of a line-focus in a rotating anode tube not only affords the advantage of a small dimension in the direction of rotation but also permits the use of considerably high energies, thus producing the maximum sharpness in definition due to material reduction in exposure times.

Since the quality of a radiograph is dependent on the size (smallness) and shape (line-focus design) of the focus and on the specific rating capacity of the tube (to reduce exposure time to a minimum), the rotating-anode tube enjoys both of these advantages. With it instantaneous ex-



(A) (B)

FIG. 136. CHARTS SHOWING MINIMUM BLURRING WHEN USING (A) A FIXED-ANODE TUBE, AND (B) A ROTATING-ANODE TUBE.

posures of radiographs of moving objects or viscera, such as lungs, heart, stomach, etc., are realized with the minimum of unsharpness resulting from movement and geometrical dimensions of the focal spot.

Owing to the short duration of these exposures the milliamperage through the X-ray tube can not be determined with an ordinary milliammeter. A ballistic type of milliampere-second meter will answer this purpose very satisfactorily.

Assuming a mean velocity of 5 mm per second for the moving visceral part and a part-film distance of 15 cms, a comparative difference in the magnitude of minimum blurring with different exposures made (a) with a stationary anode tube, and (b) with a Rotalix tube may be observed in the charts presented in Fig. 136.

It has been shown* that in order to obtain a p-fold improvement in the quality of the tube, the anode should rotate at such a speed that the path covered by it during the exposure t is at least

$$p^2 f = 2\pi nrt \qquad mm. \tag{109}$$

or,

$$p = \sqrt{\frac{2\pi nrt}{f}} \text{ fold.} \tag{110}$$

where f is the focus breadth in mm, n the number of revolutions per second, and r is the radius of the focus track.

A comparative improvement of the rotating-anode over that of the stationary anode is given as

p = 9 for uniform load.
p = 8 for a load with three-phase current.
p = 6 for a load with full-wave rectified current.
p = 4 to 6 for a load with single-phase alternating current.

At present two distinct types of Rotalix tubes are available through Philips Metalix Corporation. Of these, the second type, which is obtainable in ratings of 50 KW-second, and 200 KW-second, does not require

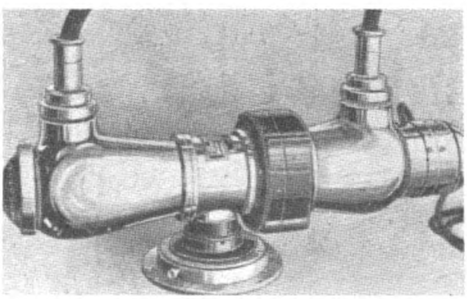
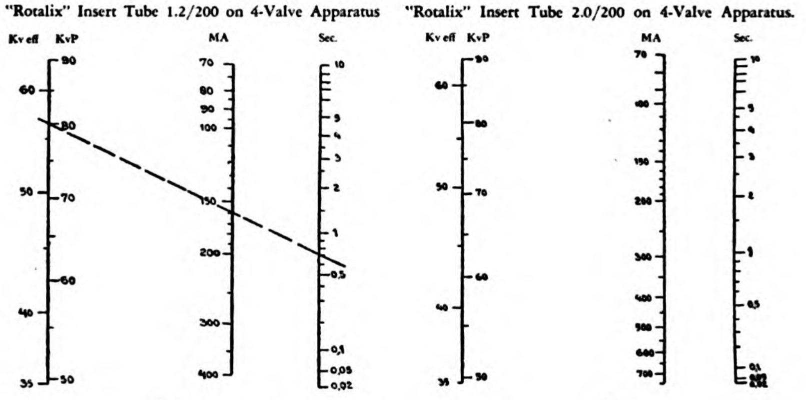


FIG. 137, ROTALIX 200 KW-SECOND TUBE.

any external device for cooling the anode. The 50 KW-second tube, especially designed for tuberculosis and heart work, is available in two focus

*A. Bouwers, Physica 10, 1930, page 125.

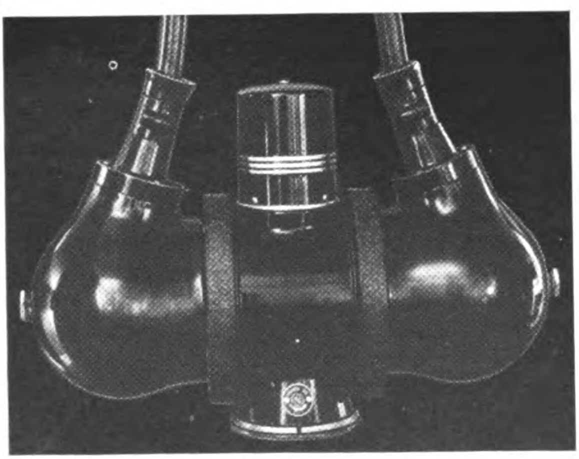
sizes, 1.2 mm, and 2 mm. The heat radiation from the anode is effected by means of the massive copper shank behind the tungsten target. With this tube, as many as 20 radiographs can be taken per hour. The 200 KW-second Rotalix tube is furnished with a copper cooling element demountably attached to the anode stem. Owing to its large volume, the cooler possesses a large heat capacity. Hence, with the use of this tube, an unlimited number of exposures can be made per hour. The tube comes with two focus



(A) (B)

FIG. 138. RATING CHARTS FOR ROTALIX TUBES.

sizes — 1.2 mm, and 2 mm. These tubes are also constructed with shock-proof shields, which also offer protection against X-ray radiation. Fig. 137 gives an X-ray-protected shock-proof Rotalix tube, and Fig. 138a and b present the rating charts for Rotalix tubes with 1.2 mm and 2 mm foci, operating on four-valve apparatus.



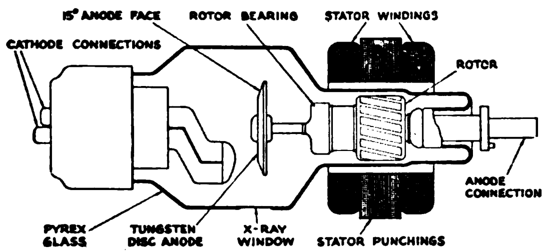
(A) DOUBLE-FOCUS ROTATING ANODE TUBE.

FIG. 139. MODEL RT1-2 ROTATING-ANODE COOLIDGE TUBE.

To determine the rating of the Rotalix tube, for instance, for 1.2 mm focus tube, a straight line is drawn to pass through all the three scales. The points of intersections will give the corresponding values of the possible rating in kilovolts, milliamperes, and in seconds. In the example shown, the line arbitrarily drawn across the chart in (a) gives a rating of 80 Kv.P., 160 M.A., and 0.7 second.

Rotating anode tubes are also manufactured

by General Electric Company, and the type that has been available since 1936, shown in Fig. 139, is a diagnostic tube with double foci, either of which may be used selectively. Because its focal spot area is about one-sixth that required with that of a stationary anode for the same exposure



(B) DIAGRAM OF ROTATING ANODE TUBE.
FIG. 139, MODEL RT1-2 ROTATING-ANODE TUBE.

conditions, the tube offers the advantage of permitting the application of considerably larger loads, thereby reducing the exposure times to minimum values. The unit is immersed in oil and sealed hermetically within a shock-proof and X-ray protective earthed container.

4. X-Ray Shielded Shock-Proof Tubes.—While with older methods of X-ray shielding open-type lead-glass bowls, or, unwieldly lead-lined boxes and drums were employed, the problem of embodying a complete X-ray protection in X-ray tubes to obtain increased flexibility of use and in manipulation has not been solved until the introduction of the first built-in X-ray protective shield.

In the year 1927, the Metalix tube incorporating a built-in X-ray protection became commercially available. The significant feature of the tube is to combine the advantage of a chrome-iron metal discharge chamber enveloped in a lead jacket of proper thickness with that of electrode design of suitable dimensions and construction. The arrangement makes possible the interception of all stray and stem radiations, permitting only those rays confined to the useful X-ray beam. The tube further enjoys the advantage of a line-focus, and possesses relatively high electrical stability.

Ray-proofing has now become a general trend in the manufacture of X-ray tubes of almost all makes. Those manufactured by General Electric X-Ray Corporation embody a lead cylinder completely surrounding the central active portion of the tube, and extensions of a lead-impregnated material covering the rest of the glass portions. Thus, both the secondary and stem radiations are reduced to a minimum. It is claimed that the effectiveness of this shielding is equivalent to that afforded by 1/16 inch thickness of lead sheet placed in direct radiation of the useful X-ray beam. Aside from ensuring the tube with added mechanical strength, and minimum danger of accidental breakage, the ray-protective covering possesses still another function in that it effects adequate protection against puncture due to a spark-over from a grounded object in the vicinity of the tube. All Coolidge XP series of diagnostic tubes are furnished with X-ray protective shields that meet with the recommendations of the International Safety Committee on X-Rays.

Subsequent to the appearance of X-ray tubes with protective shields to definitely eliminate the sources of X-ray danger, the impetus to the development of tubes with 100% electrical safety has brought about the embodiment of a grounded metal casing around the entire X-ray tube. The casing has an enlarged portion at each end of the tube in vicinity of the electrode terminal, the diameter of which portion is 2.7 to 5 times that of the cathode terminal or the radiators at the anode end. This affords the necessary spacing between the tube head and the metal casing so that the distribution of the electrical field which exists around the tube is reduced to a minimum.

The Metalix shock-proof shields are insulated from the tube terminals by an air-insulating space, while those manufactured by General Electric employ the principle of oil-insulation. Both types provide absolute protection against high tension. But, it is obvious that the oil will further offer the advantage of cooling the tube as well as precluding the possibility of electrical breakdown.

Heavily insulated flexible shock-proof cables feed the high tension into the metal shield, which, being at ground potential, provides a complete electrical protection. The cable consists of a copper conductor, whose insulation contains multiple layers of varnished cambric impregnated with special insulating oil of the same type as that employed for cooling the anode. Covering this externally is a flexible metallic braiding, making a mechanical connection with the protective casing of the X-ray tube.

With such a tube, which combines X-ray protection with 100% electrical safety, it becomes an easy matter to manipulate the tube in any desired direction. Owing to the absence of high tension danger, the tube may be placed against the patient's part, during therapy or radiography, without fear of electrical shock. Thus, the radiation can be directed more accurately to specific regions under investigation.

An oil-immersed X-ray unit presents other inherent advantages in that its electrical characteristics and X-ray output are independent of the climatic conditions, since no "live" portions from the tube are exposed to the surrounding atmosphere. In view of this latter fact, no corona discharge or ozone (which condition is prevalent with air-cooled type tubes) is produced in the X-ray room. It is further claimed that the apparatus, owing to its perfect electrical insulation and robust construction, can even function submerged in water.

Among European radiological products are also represented shock-proof and ray-proof X-ray tubes, and, of the latter, the Goliath Protex-ray tube is provided with a radiator of special construction. The tube is rated at 10 KW. The Andrews shock-proof model is a Protex-ray tube immersed in an insulating oil and sealed in an earthed metal casing. The tube is capable of continuous operation at 110 Kv.P. and 4 M.A., and measures only 19 inches long and 5 inches in diameter.

One of the French products is represented by Pilon oil-immersed tube. The tube, despite its remarkably small size, operates at 100 Kv.P. and 100 M.A. for short time exposures. The earthed metal vessel, which measures about 12 x 8 x 8 inches, contains oil with the tube completely immersed in it.

5. Radiographic Quality of An X-Ray Tube.—In a previous section, we have already shown in the light of specific load-carrying capacity considerations of an X-ray target that the quality of a radiograph is largely dependent on the effective focal spot area. It was further observed that the most favorable type of focus which will conform to the requisition in the attainment of the above quality factor is the line-focus with the principal ray projecting at an angle of 20 degrees to the target face. At this angulation, a line-focus can be impressed with a load nearly twice that afforded by a circular focus having an equal effective focus area. Since in our discussion on the quality factor the actual focal spot size is not as much of importance as the type of focus, its specific capacity, and the angular relation between the focus and the X-ray beam, the sharpness of definition in the radiograph is determined by the amount of the permissible number of watts per square millimeter of the effective or projected focus area. Bouwers* terms this relation as the *"radiographic quality."*

The relation of the specific capacity C_s may be given in an equation form as

$$C_s = \frac{W}{A} \tag{111}$$

where W is the total load-carrying capacity of the focus in kilowatts, and A is the area of the effective focus in square millimeters as projected from a line-focus tube. But, A is equal to the actual focal area multiplied by $\sin\theta$, *viz.*, the sine of the angle between the principal ray and the focal surface.

The *"quality"* of a good diagnostic X-ray tube with stationary anode (which can usually carry a load of 200 watts per second per square millimeter of the actual focal spot area) is then given as

$$Q = \frac{C_s}{\sin\theta} = \frac{.2}{\sin\theta} \tag{112}$$

With a line-focus the principal ray projects perpendicularly to the long axis of the tube, making a 20-degree angle with the target face. The projected focus, then, corresponds to very nearly 1/3 (as $\sin 20° = .34$) of the actual focal area, and, hence, the quality of the tube will be given as

$$Q = \frac{0.2}{.34} = 0.6 \text{ approx.}$$

For a circular focus of 45-degree angle, the effective focal area is .707 (as $\sin 45° = .707$) times that of the actual focus. Hence, the quality of a circular focus tube will be

$$Q = \frac{0.2}{.707} = 0.28$$

*A. Bouwers, Radiology, Vol. 16, 1931, p. 353.

It should now be obvious that the quality factor for a rotating-anode type tube (in which line-focus feature is adopted) having a target angle of 15° to the vertical will be comparatively higher than that of a line-focus tube with stationary anode, as will be shown by the expression

$$Q=\frac{0.2}{\sin 15^\circ}$$

$$=\frac{0.2}{0.259}=.77$$

which would mean that the tube has a specific load capacity of about 250 watts per sq. mm. This latter figure is also found by equating the two proportional factors together as

$$0.6 \quad : \quad 200 \text{ watts} \quad :: \quad 0.77 \quad : \quad X$$

and,

$$X=\frac{200\times.77}{.6}$$

$$=\frac{154}{.6}=258 \text{ watts.}$$

A stationary anode tube having a quality factor less than .5 should, then, be discarded.

In practice, the measurement of "*quality*" of an X-ray tube is made by first determining the effective focal spot area by means of a pin-hole camera (described elsewhere) and then measuring the load-carrying capacity of the tube.

A simple method for determining the quality factor is described by Bouwers in an article on "*Measurement of Quality,*" Philips X-ray Research and Development, 1933, page 154. The essential feature of the experiment is to light the tube filament for a few milliampere emission, and, after darkening the X-ray room, to sustain the tube at a constant potential of, for instance, 50,000 volts. The milliamperage is gradually increased until a red glow (due to heating by electron impact) is seen on the focal spot (by means of a mirror arranged at an angle underneath the X-ray tube). This point is reached at a temperature of about 1300°C, which is produced by half the load required to raise the target temperature in one second to 2600°C.

Assuming, in this experiment, that the current necessary to raise the target temperature to 1300°C was 40 milliamperes at 50,000 volts, it follows that

$$\frac{W}{2}=50{,}000\times.04= 2000 \text{ watts.}$$

or,

$$W = 2 \times 2000 = 4000 \text{ watts.}$$

which value represents the precise rating of the tube in question.

If the tube has an effective focal area of 2.6 x 2.6 = 6.7 mm., then its quality will be given as

$$Q = \frac{40}{10 \times 6.7} = 0.6$$

which quantity is in accordance with the first conclusion.

The significant point in the above disccussion lies in the fact that since the ratio of the quality factors between the line-focus and the circular focus tubes is respectively 2.14 : 1, for a given sharpness of definition, the specific load-carrying capacity of the line focus is over twice that permissible through a round focus tube. The advantage of the higher specific load capacity of the line-focus tube can be applied to obtain a better definition in the radiograph. This is achieved by increasing the target-film distance, and by decreasing the time of exposure, which is a determining factor in the elimination of unsharpness due to movement of the object.

6. R-Output of X-Ray Tubes.—The generating quality of an X-ray tube may be determined by a consideration of its load capacity in relation to the corresponding X-ray output. Obviously, the higher the compared value of the tube output in respect to input energy the factors causing this relation will be considered as being applicable, for a favorable tube performance, to the type of tube in question. With a high perecntage X-ray output it will be readily seen that the effect will produce a considerable reduction in exposure time with a consequent acquisition of sharpness in radiographic definition. In the case of therapy work, the shorter treatment time will accrue a diminished strain on the X-ray apparatus, with the resulting prolongation in the life of the X-ray tube, or of rectifying tubes, if these be included in the apparatus.

A comparative study of roentgen-ray output of different X-ray generating apparatus and circuits reveal that the variations in r-output are not altogether independent of the type of generating equipment, the waveform of the high tension current and voltage, and design and material of the tube envelope. Differences in the radiation output may also be found where X-ray equipments of different manufacture are compared, and where differences in aerial system, rectification, type of valve and X-ray tube, and mains supply, are existent.

From the data obtained by different investigators, and in the writer's laboratory, it is quite obvious that the variations in the quantity and quality of the X-ray output is intimately related to the generating equipment. The heating of the glass envelope during operation of the tube will, on some machines, cause an increase in X-ray output, while in others, the converse will be realized. The latter condition is due to the fact that when the pyrex envelope is cold (at a temperature below 100°C) it retains its properties as a good insulator, and the stray charges collected on the inner surface of the bulb produce a negative potential difference equal to the peak

potential of the cathode. During the falling of this voltage, the resident electrons on the glass walls, producing a grid action, effect a distorting influence on the electron stream, and even may totally prevent the emission from leaving the hot cathode. On the other hand, when the glass envelope is hot it becomes conducting, and the charges flow freely through the glass to disperse the field. This latter condition permits the current to flow across the tube not only at the peak value but also at the lower portion of the potential wave. Consequently, the r-output of the tube increases.

While the *constant potential generator* (which contains a ripplage* of 0.2 to 2 per cent per milliamperage), Fig. 95, offers by far the most ideal solution to the problem of X-ray output, the latter factor, on pulsating rectified current, is governed to a considerable extent by tube design and the material of the envelope. Since no modifications are involved in the wave form of a constant potential circuit, the radiation output is always uniform regardless of the thermal condition of the tube envelope. With this type of circuit, however, to secure the best performance of the X-ray tube, the ballast resistance should be kept at a minimum value in order that the condensers may sustain a constant normal potential.

Next most efficient type of X-ray generator is that with a *voltage-tripling* (Witka) *circuit,* given in Fig. 100. In this circuit, the tube potential is alternately supplemented to $3V$ by the combined voltage of the condenser, valve tube, and the transformer, and then reduced to V, the potential of the transformer. The reduction of the tube voltage to V allows a rest period whereby the tube is relieved of the higher potential stress. The circuit, however, has not found wide commercial application, owing to limitations imposed upon it by problems of adequate insulation of the valve filament transformers from the primary circuit, cost of maintenance, etc.

An apparatus which is third in order of r-output is the one equipped with *voltage-doubling circuit* (Villard), illustrated in Fig. 94. As in the Witka circuit, the current through it is of pulsating rectified type. Employing very high tension, the Villard circuit is extensively used because of its output as regards to r and half-value layer, which are substantially the same as that produced on constant potential circuit (Greinacher). Since only one-half of the X-ray tube tension is furnished by the transformer, the necessity of insulating the latter to the full tube potential is obviated.

For all practical purposes, the differences in r-output between four-valve rectified, half-wave tube rectified, or mechanically rectified circuits do not exceed 5 per cent.[1] Variations in output may arise, however, in the quantitative comparison with different types of tubes energized on different circuits. For instance, it has been shown[2] that with a water-cooled therapy tube used on half-wave rectified circuit the radiation output per milliampere is practically same as that given by an air-cooled tube energized on a voltage-doubling circuit, while the latter circuit with water-

*Defined as the ratio of the difference between the maximum and the minimum values to the average value.

1,2. M. J. Gross & Z. J. Atlee, Roentgen-Ray Output, Amer. J. of Roentg. and Radium Therapy, Vol. XXX, No. 2, August, 1933.

cooled tube produces as high as one-and-a-half times the r-output afforded by an air-cooled tube on a half-wave circuit.

In a comprehensive publication on the comparison of the roentgen ray output as a function of the applied voltage, Taylor, Singer, and Stoneburner[1] maintain that irrespective of the voltage wave form the output per effective milliamperage for any given effective (r.m.s.) voltage remains same. That is, a roentgen tube impressed with any given effective voltage and operated on a variety of voltage wave forms gives substantially the same roentgen-output per effective milliampere. There are, however, two most obvious factors involved as being responsible for the variations in r-output — one being the glass absorption, and the other being connected with the distortion of the voltage and current wave forms caused by the tube itself.

Experimental results have shown that of the several tubes having pyrex envelopes of various thicknesses and metal-centered tubes under investigation the output from thin glass tubes has been 11 to 15 per cent greater than that from thick-walled tubes operated on constant potential circuit, whereas the metal-centered tubes have shown a decreased output of 15 per cent compared to thick glass tubes. A pyrex envelope of 1/4 inch in thickness offers, at 200 Kv.P., an inherent filtering characteristic equivalent to 0.2 mm of copper, which is of no disadvantage in therapeutic work.

The r-output variations from a thick-walled air-cooled tube on a circuit other than that of constant potential amount to as high as 20 per cent lower until the glass attains a steady thermal state. This decrease is caused by the distortion in the wave form of the current and the voltage arising from the interaction of the tube current and the transformer primary voltage, which condition, in turn, is due to the grid action of the scattered electrons on the glass envelope before it becomes warm, when, the effect is annihilated, resulting in a steady tube output. It has been observed, however, that, after this stable state is reached, the r-output per milliampere of a water-cooled tube may be from 11 to 25 per cent higher than that of an air-cooled tube of the same rating. With the exception of output differences due to glass absorption, tests made on air-cooled therapy tubes of different manufacturers indicate that variations in the amount of distortion in the wave forms of the electrical factors are practically same. Tubes of the same type and manufacture are found to give practically the same r-output when operated on a given type of generator. However, maximum variations of 28 per cent on full-wave rectifier, 32 per cent on half-wave valve-tube rectifier, and 35 per cent on mechanically rectified apparatus (rectifying 20% of the cycle)have arisen between the output of individual roentgen tubes operated at 180 Kv.P. for test purposes.[2]

Comparative measurements made on r-outputs for the metal-centered and for the thin-walled therapy tubes indicate that the output per milliampere of the former tube is about 35 per cent less than that of the latter type, and 16 per cent lower than that given by thick-walled tube. The lower

[1]Comparison of High Voltage Roentgen-Ray Tubes, Bureau of Standards Journal of Research, March, 1934, p. 378.

[2]Taylor, Singer, and Stoneburner, Bureau of Standards Journal of Research, page 381, March, 1934.

output difference of the metal-centered tube may be attributable to the preclusion, by the metal chamber, of the stem radiation dominant with all-glass envelopes and amounting to 10 to 20 per cent of the total radiation.[1]

Frequently it is desired to ascertain the wave-form of the voltage or the current through the X-ray generator (operating on a pulsating circuit), as by means of which information an adequate panacea can be found to fluctuations in tube milliamperage during operation, to varying r-output, and to general instability of generator performance. Since the cathode ray oscillograph can respond to all ranges of frequencies, it can be advantageously used in obtaining either the voltage or current wave.

The manner of wiring the oscilloscope to the high tension circuit is diagrammatically given in Fig. 140.

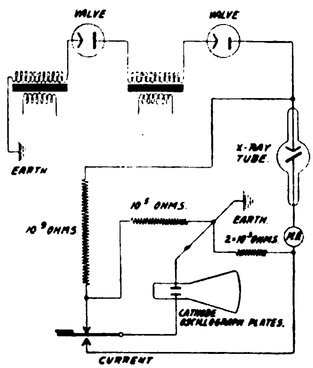


FIG. 140. CIRCUIT DIAGRAM FOR OBTAINING THE VOLTAGE AND CURRENT WAVES. (SLACK & SMITH[2])

Before we digress from the subject of X-ray output, it will be well to recall that the radiation output factor is a direct function of the atomic number of the radiator. For example, Gold having an atomic number 79 (higher than that of Tungsten, for which it is 74) will increase the r-output 10 per cent over that of tungsten at a given load, while this increase from Thorium and Uranium targets will amount to 25 to 30 per cent. The principal objection in their use as target material, however, is of the low melting point of Gold, and of high vapor pressures of either one of the latter two elements, which property will seriously tend to disturb the tube stability. Hence the use of these elements as target material is restricted to special research work.

7. Difficulties Experienced With X-Ray Tubes.—Of the numerous factors that cause complications in successful tube performance, we have already discussed in detail some of the principal difficulties arising from inadequate structural details of tube design. Still other common irregularities component to sources of electrical disturbances and impeding the attainment of the maximum usefulness of an X-ray tube will be considered in the accompanying discussions.

(1) *Bias* is a condition effected by the accumulation of scattered electrons on the inside surface of the glass envelope, charging it to a high negative potential. The effect is influenced by the shape and position of the focusing cup in relation to the filament as well as to the glass envelope, and by the spacing between the electrodes. A tube with a high bias permits the passage of electrons only at high voltages, thus restricting the production of X-rays to the high voltage portion of the pulsating current wave. For therapeutic work, where the tube operates at a high peak voltage and relatively at low average milliamperage, a tube with a high bias, therefore, will produce more of the useful X-rays. On the other hand,

[1]Coolidge, W. D., & Moore, C. N., General Electric Review, April, 1917, page 272.
[2]Radiology, Vol. XXII, No. 3, pages 280-285, March, 1934.

for diagnostic work, where lower kilovoltage with comparatively higher milliamperage ranges are utilized, the use of a low bias tube is highly desirable, as with excessive bias a tube may even refuse to pass current. Again, the question centers around sound engineering and correct design of tube structure.

(2) *Glazed Focal Spot* is a condition resulting from overload of the tube. If this is not caused by inadvertent application of power, the possible cause may lie in the error in timing mechanism, milliammeter, or autotransformer rating charts. Therefore, these items should be checked in order to prevent the recurrence of the overload. Tubes affected with glazed focal spots should be operated at relatively lower load energies.

(3) *Cracking* of the focal spot may frequently occur as a result of tube operating at high millamperage. If the condition does not affect the proper performance, the tube should be continued in service as long as it shows no signs of instability when operated at full load. As the tendency of this effect increases with tube life, when cracks are detected on the target the life of the tube may be increased if the latter is used at lower load ranges than it normally can withstand. Should the crack ultimately extend through the tungsten to the copper anode, the tube may then be considered as useless.

(4) *Melting of the copper* immediately behind the tungsten focal spot may occur as a result of excessive heating of the anode by an overload. The pressure produced behind the focal spot button by the expansion of the copper on melting may ultimately cause the tungsten to crack. Subsequent use of the tube in this condition will cause the copper to gradually ooze to the surface, spreading over the focus. Consequently, the radiation quality of the tube will be lowered owing to the emission characteristics of copper. Continued use may also cause the volatilization of the copper, producing an increase in tube pressure and impairing the stability of performance. Such a tube should unquestionably be discarded. However, a tube with an all-tungsten anode (as in standard tubes,) having cracked or pitted surface may be continued in service until excess gassiness is indicated.

(5) *Gassiness* is not necessarily an indication of the presence of air in the tube, but it may be due to the liberation of occluded gas by excessive heat localized at some part inside of the tube. A tube operated at high voltage has this tendency, but subsequent use will obviate the effect. With modern X-ray tube, where extreme care and precision is exercised in eliminating all foreign materials adherent to metal or glass parts, the phenomenon is rarely met.

(6) There may be other indications that may produce doubt in the mind of the operator as to the satisfactory condition of the X-ray tube. Of these, *purple* or *apple-green fluorescence* of the glass envelope is due to the impact of the scattered electrons from the anode. The condition remains without significance.

Another phenomenon that very rarely occurs is the appearance of *incandescent* spots on the target face. This is assigned to incomplete removal, during processing of the tube, of the foreign matter normally adhering to the surface of the metal, or to minute particles accidentally lodged thereon. The quality of the X-ray tube will not be affected by this

phenomenon, and therefore, the latter should be ignored. With constant operation, the spots will eventually disappear.

Finally, still another factor of rare occurrence is the *blue discoloration* of the target surrounding the actual focal spot. The condition is produced during early stages of exhaust, and is permanent, and hence, can not give rise to any ill effects.

8. X-Ray Tube Life; Puncture.—It will be quite difficult to predict without reservation the exact duration of the useful life of an X-ray tube. In view of the fact that X-rays are made under varying conditions dependent upon the part of the operator, design and construction of the tube and electrical factors controlling its output, location of the generating apparatus, mechanical abuse or breakage of the tube by inadvertent handling, etc., it is almost impossible to determine just how long a given tube will last. The normal life of earlier X-ray tubes ranged from 150 to 250 hours of actual operation, but with modern X-ray tube, which combines mechanical precision with high quality tube material, the extension of this characteristic to as high as 2000 hours is not unexpectable, as proven by actual cases.

Some of the principal causes that bring an end to the life of an X-ray tube are ascribable to gassiness or punctures. This is specially true with roentgen therapy tubes which are usually operated at very high tensions. The envelope of such a tube, when cold, is under both a longitudinal and a radial stress. The latter stress is effected as a result of electrostatic charge produced by diffused electrons lighting on the inside surface of the glass envelope and charging it to a high potential in respect to its outside surface. Consequently, an extremely high electrical strain between the two surfaces of the glass will be built up. Should these radial stresses exceed a critical point so that the glass can not withstand any longer, a prompt puncture occurs at whatever point on the envelope the charge is concentrated. Majority of the punctures occur in the cathode half of the bulb facing the target.

Punctures may occur even under conditions of very close attention, but they may be made less frequent or entirely prevented by increasing the dielectric strength of the tube envelope — which means to increase the thickness of the glass. The second solution is to completely eliminate secondary electrons from the glass, by providing an electron trapping shield (Sec. 1, Chap. XIV) around the anode, and to avoid cold cathode discharges by lighting the tube filament previous to the application of high tension to the tube. With tubes whose envelopes are heated up before the X-ray tube is energized to emission, the risk of puncture is considerably reduced, as the electrostatic field on the envelope tends to equalize itself owing to the electrons flowing freely through the glass.

Other causes of tube failure as a result of puncture are ascribed to dusty tube envelope, to tubes operated in proximity of sharp points, to high tension surges, and to a temporary electrical connection established between the tube envelope and the ground while the tube is being operated (that is, by accidentally touching the tube). Frequently, an excess metallic deposit on the inner surface of the tube envelope may contribute to the puncturing of the tube.

It must be pointed out, however, that with modern X-ray tubes — especially in the case of shock-proof tubes — the tendency for tube puncture is practically obviated. This is specially true with tubes immersed in oil, which effects an electrical insulation of high dielectric strength against any possibility of a flash-over.

QUESTIONS ON CHAPTER XIV

1. (a) Explain fully the effect produced by the secondary electrons on the operative characteristic of the X-ray tube. How does the interelectrode spacing alter this effect?
   (b) How does proper cooling system increase the load rating of an X-ray tube?
   (c) On what factors is the temperature of the focal spot dependent?
2. (a) An X-ray tube, having a tungsten focus area of 24 sq. mm and a thickness of 3 mms, receives 600 watts. If the density of tungsten is 18.8 grams per Cc, specific heat 0.036, and its melting-point 3370°C, how long can the tube withstand this power before the tungsten just starts to melt (assuming that 40% of the heat energy is conducted through the copper stem)?
   (b) Describe the different methods of target cooling. What advantage has oil-cooling over water-cooling?
   (c) How are the maximum ratings of exposures and the frequency with which they can be repeated determined?
   (d) Consulting chart in Figure 133, determine the maximum number of exposures that can be made at 50 KV.P., 40 M.A., and 2.2 seconds, with a water-cooled Coolidge X-ray tube.
3. (a) Account for the distinctive features of a rotating-anode type X-ray tube.
   (b) If an X-ray tube with rotating-anode is operated on a three-phase current and its target covers a displacement of 75 times its 2-mm focus breadth of a track radius of 2.5 cms., find the least exposure time for which the tube may be loaded.
   (c) Enumerate the factors or means responsible for making it possible to produce a 200-KW-Second X-ray tube.
   (d) How does the rotating-anode X-ray tube render the reduction of exposure times to minimum values?
4. (a) What are the requisite elements entering into the X-ray shielding and shock-proofing of an X-ray tube?
   (b) Account for the advantages presented by ray-proofed and electrically safe X-ray tubes.
   (c) Determine the radiographic quality of an X-ray tube having a focus of an area 16 sq. mm at 20 degrees with the vertical and a load-carrying capacity of 3.2 KW.
   (d) Prove that the specific load-carrying capacity of a line focus tube is approximately twice that permissible through a round focus tube.
5. (a) What effects have the focus area, target angle, atomic number of the target material, and the r-output of an X-ray tube on the radiographic quality?
   (b) How do the outputs per effective milliamperage vary in constant potential, full-wave, half-wave, voltage-doubling, and voltage-tripling generators?
   (c) How does the envelope of the X-ray tube affect the r-output? Discuss fully.

(d) What conditions give rise to interaction of the tube current and the transformer primary voltage to produce a diminution in the r-output from a roentgen tube?

6. (a) What part does bias in an X-ray tube play in restricting the production of X-rays?

(b) A certain X-ray tube has cracked tungsten focus, and produces apple-green fluorescence during operation. To what condition of the tube are these indicant?

(c) Does continual use of the tube in (b) improve its performance or impair its useful life?

(d) State some of the causes and prevention of tube puncture.

CHAPTER XV

X-RAY RADIATIONS

One of the most outstanding achievements in the realm of pure science of the nineteenth century is depicted in the discovery of X-rays by Wilhelm Konrad Roentgen, toward the close of the year 1895. Engaged as a professor of physics, in the University of Wurzburg, Roentgen's experiments primarily centered in the investigation of electrical discharge phenomena through rarefied gases, of which much had been learned already. Pluecker had noticed the phosphorescence produced by the cathode rays on the walls of the discharge tube. Lenard had succeeded in conveying the cathode stream out of the tube through an Aluminum-foil window. Still earlier, Wilhelm Morgan had already achieved an extremely high vacuum in his discharge tube, which would not pass any discharge when subjected to the potential supplied by his electrical equipment at the time—a condition which is an essential characteristic with the modern high-powered thermionic X-ray tube. It was through these advances already surrounding the background of the impetus driving Roentgen that he was led to realize his crowning achievement through a fortuitous discovery.

1. Discovery of X-Rays.—It was while studying the nature of the cathode rays as to whether or not they were associated with the emission of ultra-violet rays that Roentgen first observed this new emission which he later called X-rays. The apparatus was set up in a darkened room, where visible light of any nature, even that from his cathode ray tube, which was enclosed in a closely fitting black paper, was excluded. But, to his astonishment, a piece of cardboard screen impregnated with Barium Platinocyanide and lying on the table near the apparatus was glowing brilliantly. The screen fluoresced equally brightly whether its treated surface or the back surface was held against the tube. Moreover, the greenish-yellow fluorescence was distinctly observable even if the screen was held within a radius of eight or ten feet from the tube.

The new radiation, he observed, traversed through almost any object to an appreciable extent. A large volume of book interposed between the tube and the screen had no effect in the fluorescence of the screen. Wood, mica, celluloid, and amber were very transparent to the radiation, while Aluminum, Tin, and Copper sheets were less amenable to the rays. But, the most exciting moment of his experiments occurred with his observation of the bones of his fingers interposed between the tube and the treated screen while holding it.

Roentgen, then, proceeded to make an extensive study of the source and character of these rays. He was soon confirmed that when cathode rays were incident upon matter in the evacuated tube a new radiation of entirely unknown character was produced. Thus, Roentgen named it X-rays. The emission was more prominent from the anode, or the positive electrode, than any other part of the tube. A photographic plate exposed to the rays

was readily affected. Thus, realizing the possibilities of the applicability of this new radiation to photographing the intrinsic structures of different materials, Roentgen began to devote most of his time to X-ray photography. Among the X-ray pictures that he made of many objects are the photographic images of his hand, a pocket compass, a door knob, a key, and his shot-gun. In recent years, with modern equipment, radiography has been so extended as to provide us a diagnostic prototype not only in medicine but in industrial problems.

2. The Nature and Properties of X-Rays.—Prior to Roentgen, other investigators, such as Hertz and Lenard, however, had already observed that cathode rays had peculiar penetrating power through matter intercepting their path of propagation, and that photographs (shadow pictures) of objects traversed by these rays could be made on the photographic plate. They failed, however, to make the application suggested later by Roentgen, who utilized the radiation emanating from the anti-cathode (X-rays) instead of that from the cathode (cathode rays). The significance of Roentgen's application readily becomes of obvious importance in that cathode rays are negatively charged particles of electricity and can penetrate matter, at the most, a few millimeters, while X-rays are radiations of transverse electromagnetic vibrations of the same nature, in many respects, as visible light; and, due to their extremely short wave-lengths, X-rays can penetrate matter to a depth of many centimeters, depending on the density and the character of the material traversed.

The penetrability by X-rays varies with different substances. The higher the atomic weight of a substance the more opacity it offers to penetration by X-rays. Metals, such as Aluminum, Magnesium, and thin sheets of Copper, and Zinc, and most organic substances such as wood, fibre, cardboard, bakelite, cotton, etc., are readily traversed by X-rays. Alkali Earth Metals, Calcium, or Barium, however, are not easily penetrated; hence, advantage is had in using a colloidal mixture of Barium Sulphate (which can not be assimilated in the body) emulsion in the radiographing of the alimentary canals, such as the esophagus, stomach, small intestine, and the colon, including the appendix.

Since a radiograph is the "shadow picture" of a part exposed to X-rays, the blackness of the "picture" will depend on the penetrativeness of the radiation, which, in turn, varies with different densities constituting the part radiographed. X-rays of ordinary intensity, such as for radiographic work, do not penetrate Barium Sulphate to an appreciable depth. Thus, the softer structures surrounding the Barium mixture become more amenable in contrast with the Barium content when radiographed on a film, rendering the observation of an infected, or an involved, part more effable by the formation of a peculiar shadow in the image. A bone structure, mostly constituted by Calcium, is less penetrable than the surrounding softer tissues, and when viewed through a fluoroscope, a darker shadow for bones is exhibited in contrast with that represented by the softer tissues. Thus, a broken, or, a disintegrated, bone is readily discriminated from a normal bone when examined with a fluoroscope, or radiographed on a film.

In the diagnosis of the inner organs, such as the lungs, heart, liver, stomach, intestines, etc., the softer tissues are more readily penetrated by

X-rays than those of the denser parts. The air content of some structures render them less dense, and hence more penetrable by X-rays. Thus, the broncheal and alveolar cavities in the lungs afford an easy visualization in respect with the tissue of the lung proper, which, in turn, stands in marked contrast with the interposed denser heart structure. The air sinuses, such as the maxillary, frontal, and other accessory sinuses, including the mastoids, and the pus pockets or cyst formations along the dental roots are readily distinguished from the surrounding structures. Frequently, the air content of the colon, however, renders the examination of the gall-bladder more difficult, as the latter becomes distended and its location altered.

In discussing the nature of X-rays we may mention that the radiation is analogous with the waves of sound produced by the impact of bullets on a sound-producing target, while the bullets represent the cathode rays. One should be able to see, now, the distinction of cathode rays from X-rays in the same aspect as the difference between the bullets and the sound waves they produce on the target.

It will now be appropriate to recapitulate some of the principal properties of X-rays with which the scope of this text is concerned.

(1) X-rays are invisible electromagnetic vibrations.
(2) X-rays do not possess electrical polarity, and, therefore, are neutral radiations.
(3) X-rays have wave-lengths ranging from 0.04 to 1100 Angstrom units.
(4) X-rays are propagated from the anode in straight lines.
(5) X-rays propagate with a velocity of 3×10^{10} centimeters per second, as does visible light.
(6) X-rays are not influenced by electric or magnetic fields.
(7) X-rays can not be focused to a point.
(8) X-rays ionize the gas which they traverse.
(9) X-rays are capable of affecting photochemically the sensitive emulsion of the radiographic film.
(10) X-rays can produce stimulation, or disintegration, in the tissues of living matter.
(11) X-rays are capable of producing secondary radiations, and photoelectrons.

3. Production of X-Rays.—We have already observed that the sudden stopping of the swiftly-moving cathode rays is accompanied by a radiation entirely different in character from that of the cathode rays. The radiation, known as X-rays, traverses through space, or ether, with the speed of light, and penetrates almost any object placed in its path. It will be further observed that the rays in many respects are of the same nature as visible light, one principal difference being the character of their extremely short wave-lengths, and hence their spectral classification under invisible ultra-short radiations.

In an X-ray tube, as the cathode rays strike the target, or the anti-cathode (a block of metal, such as Tungsten, Platinum, or Thorium) they penetrate a few microns to its interior, where, the energy of most of the cathode particles is transformed into heat, only a small percentage, between 0.1 to 0.8 percent, giving rise to X-rays. The exact percentage of this issue depends upon the voltage and the quantity of cathode rays, and,

with certain limitations, varies as the square of the impressed voltage. The intensity of the emission is dependent on the nature of the target metal which the cathode rays bombard, and also on the voltage applied to the tube. Materials with higher atomic number, and hence of greater atomic weight, will produce X-rays of greater penetrating quality than those emitted by the lighter substances under identical voltage ranges. The impressed voltage further affects the magnitude of the wave-lengths and hence the penetrating power of the X-rays.

Despite the fact that the electrons in the bundle of cathode stream leaving the cathode all possess the same kinetic energy determined by the impressed voltage on the X-ray tube, when this energy is transformed in the target the output of X-rays will consist of a heterogeneous mixture of wave-lengths, and frequencies ranging from a maximum to a minimum. The effective wavelength of this mixture, however, varies approximately inversely as the voltage.

From the foregoing discussions it will become apparent that the production of X-rays by the impact of the cathode stream on the target of the X-ray tube is the converse of the photoelectric phenomenon. In the latter, a beam of light quanta, possessing energies dependent on the frequencies of the individual photons impinging upon the sensitive surface of the photoelectric emitter, eject electrons whose energies vary from zero to a maximum, as given by equations (92) and (94). We may express, therefore, the energy relations in the production of X-rays by an equation representing the converse of the photoelectric process; and, assuming that all the voltage energy on a given cathode particle appears as kinetic energy just before it strikes the target, and further assuming that this entire energy is transformed in the production of a corresponding X-ray photon from the target substance, we may write

$$\frac{Ve}{300} = \tfrac{1}{2}mv^2 = hf \tag{113}$$

or, simply

$$\frac{Ve}{300} = hf \tag{114}$$

in which, the corresponding values of the quantities as represented in equations (92) and (94) are conserved. It will be noted that the work function ϕ as given in the photoelectric equation is neglected, owing to the fact that in the production of X-rays ϕ is comparatively very small with respect to thousands of volts impressed on the cathode rays.

From equation (114), it becomes obvious that the energy of the X-ray photon hf varies directly as the impressed voltage on the X-ray tube. Furthermore, since this photonic energy is directly associated with its penetrating power, our previous inference that the latter quality is dependent upon the voltage is thus confirmed.

(*a*) *Soft X-Rays and Hard X-Rays.*—When X-rays first appear at relatively high pressure in a gas-filled X-ray tube, they are easily absorbed by matter, and, thus, are said to be "soft rays." In a vacuum tube, since a

constant internal pressure (vacuum) is maintained at all times, relatively low voltages applied to the tube produce correspondingly soft radiations. The flesh of the hand appears opaque when viewed with a fluoroscope, as the rays do not possess sufficiently high penetrating power. If the pressure of the gas-tube is lowered (toward vacuum), the voltage required to pass a discharge across the tube should be correspondingly increased, and the rays become more and more penetrating, until, when the effective potential is raised above 100,000 volts even the bones in the hand cast only a faint shadow on the fluorescent screen. The quality of this type of X-rays is referred to as hard.

Fig. 141 represents an atom of a heavy target metal, and for sake of convenience, the extranuclear electrons are excluded from the orbital field. If this atom is bombarded with electrons of sufficient energy to remove an electron, for instance, from the *K-level,* it will stand to reason that the resulting X-ray photon will have an energy and penetrating power greater than that produced by the radiation of an electron from the *L-level,* since it will take less energy to excite an electron from the *L-level* than from the *K-level,* where, the electrostatic force due to the nuclear charge is greater. Similarly, radiations from *M-*, *N-*, or *O-levels* will respectively possess less and less energy and longer wave-lengths, with the result that X-rays emitted from the innermost orbits of a heavy atom will be more penetrating than those given from the outer orbits.

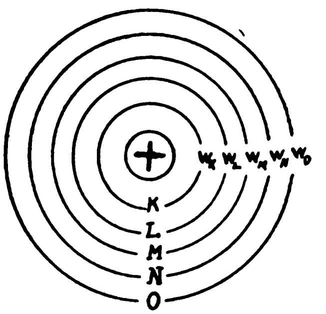


FIG. 141. X-RAY QUANTUM LEVELS IN A HEAVY ATOM.

According to *Ether-Pulse Theory,* the high velocity electrons as they collide with the target of the X-ray tube, some of them will experience an acceleration radially to the atom. In an acceleration of this type, the electron must radiate, as depicted by the electromagnetic theory. The emission embodies a succession of pulses, frequently known as *"ether pulses,"* which could be resolved into wave-trains of heterogeneous wave-lengths, depending on the impressed voltage and on what electrons are excited to emission. All materials relatively are more transparent to the shorter wave-length radiations than to those of longer wave-length. But, transcending this theory is the one offered by the quantum mechanics which imputes the penetrating quality of an X-ray radiation with the frequency conserved in the photon as emitted by the target. It is already noted that this quality depends upon the impressed voltage, and upon the target metal. The higher the voltage, and the higher the atomic weight of the target material the shorter the wave-lengths and higher the frequencies of the resulting X-rays, and hence the quality of the X-rays thus produced will be hard. X-rays with longer wave-lengths and lower frequencies are readily absorbed by matter, and therefore, they are described as soft X-rays.

Soft X-rays, produced by 10 to 20 thousand volt energy, are sometimes known as *Granz Rays,* and are used in superficial skin therapy, while hard

X-rays, which are emitted by effective voltages of over 100 kilovolts, are employed in deep therapy procedures.

(*b*) *Limiting Wave-Lengths and Maximum Frequencies of X-Rays.*—From equation (114), it was shown that the maximum frequency f with which an X-ray quantum will be liberated is strictly dependent upon the voltage V applied on the X-ray tube, since other quantities included in the equation remain constant. We may now express this relation between an applied voltage and the production of an X-ray photon of maximum frequency by equating the formula (114) for the maximum frequency f. Then, we have

$$f=\frac{Ve}{300h} \tag{115}$$

where, e is the charge on the electron, and h is Planck's constant.

Since e and h are constant for all values of the voltage V, we may substitute their numerical values in equation (115), and obtain

$$f=\frac{V\times4.77\times10^{-10}}{300\times6.55\times10^{-27}}$$

$$f=2.43\times10^{14}\ V \text{ approx.} \tag{116}$$

In the last expression, if the maximum frequency for varying values of the applied voltage V is plotted against the latter, a straight line curve is obtained, as shown in Fig. 142.

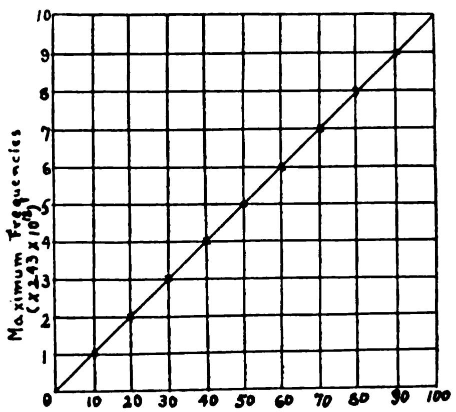


FIG. 142. RELATION BETWEEN THE APPLIED KILOVOLTAGES AND MAXIMUM FREQUENCIES PRODUCED.

By making further substitutions for f in equation (116) in view of equation (44), we may express the minimum wave-length produced by a voltage

V in the following convenient form:

$$f = \frac{C}{\lambda} = 2.428 \times 10^{14}\ V$$

from which,

$$\lambda = \frac{C \times 10^8}{2.428 \times 10^{14} V} = \frac{3 \times 10^{10} \times 10^8}{2.428 \times 10^{14}\ V}$$

or,

$$\lambda = \frac{12355}{V} \tag{117}$$

in which, λ is the minimum or limiting wave-length in Angstrom units of the X-ray photon produced by an applied voltage V in volts.

Fig. 143, originally obtained by Ulrey, represents the distribution of energy in different X-ray wave-lengths for Tungsten target at various voltages ranging from 20 to 50 kilovolts. It will be seen from this chart

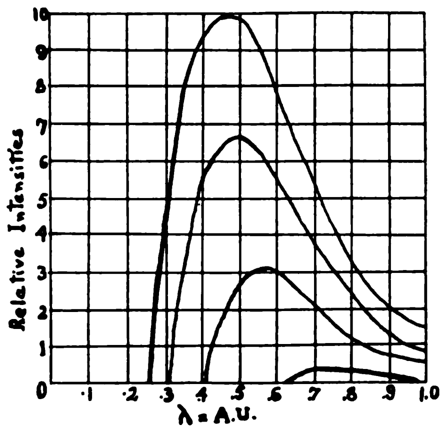


FIG. 143. X-RAY SPECITRL CURVES FOR TUNGSTEN.

that for each given curve there is a point corresponding to the minimum wave-length which gives rise to a maximum X-ray intensity. On either side of this point the intensity diminishes with change of wave-length in accordance with energy distribution.

4. The Secondary Radiations.—As the bundle of X-rays (primary rays) issuing from the anti-cathode impinges upon matter, the radiation energy is in part transformed into new radiations, and partly scattered as the original radiation. For sake of convenience, any X-ray radiation propagating from matter other than the X-ray tube target is classified as a secondary radiation. The latter radiation may be emitted from any object that is reached by the primary rays. Such objects may be the glass walls of the

X-ray tube, the anode stem, the protective shield around the tube, the cones, the patient, and any other object in the path of the primary radiation. Secondary rays, by impinging on matter, may set up tertiary waves. Whatever the character of the resulting radiation my be, it must be well clear in mind that the energy of the inciting X-rays associated with tertiary radiations must be equal or greater than the incited radiations before an emission can take place. For sake of our scope, in this text, we shall limit our discussions to two types of secondary radiations—namely, scattered rays, and characteristic radiations.

(*a*) *Scattered Radiations.*—Primary X-rays when incident upon organic matter, such as wood, wax, film, bakelite, and living tissues, may be scattered in all directions. The scattered rays have wave-lengths practically of the same magnitude as the primary rays producing them. The thicker the part of the object (possibly the patient) irradiated the more scattered radiations are produced. Some of the rays from the X-ray target pass through objects without transformation, while others are scattered in random directions. The scattered rays consist of different wave-lengths corresponding to and are characteristic of the primary rays, and, therefore, have the same photochemical effects as the primary beam inciting them. Hence, if the scattered rays are allowed to reach the photographic film they will impart to the latter a general haziness, interfering with the otherwise clear, well-defined, and sharp details of the radiographic image. The effect is due to the impinging of the secondary rays unto the film subtending radiations from directions other than that of the radial beams projecting directly from the X-ray target. Scattered radiations are generally produced by substances having atomic weights less than that of Aluminum.

The effect of scattering is especially prominent with soft tissues of the body. The greater the field of exposure of soft tissues to the radiation from the target the greater the scattering of the rays. In consequence, the image of the bone structure in the radiographic field will be blurred to a greater extent. This difficulty can be overcome, however, by using a cone of proper size to reduce the field to an area just large enough to include the part to be radiographed. In radiographing the extremities, the effect of scattering becomes insignificant, since these parts largely consist of bones surrounded by soft tissue to a comparatively small extent.

In the case of a large exposure field, as required in the radiography of the gastro-intestinal series, the spine, the pelvis, or larger organs of the body, the scattering will occur to a larger extent. Thus, to obtain the optimum contrast and detail as is usually desired in a radiograph, a device, known as Potter-Bucky diaphragm, is interposed between the film and the object to be radiographed to exclude all possible secondary rays from the film. Almost a complete exclusion of the scattered rays from the film is realized by the use of this device, thus enhancing the resultant image with optimum radiographic quality.

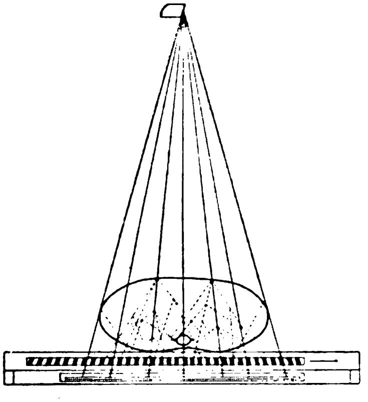
The diaphragm comprises a moving grid consisting of a series of lead strips interposed at definite intervals between strips of X-ray-transparent material such as wood, fibre, bakelite, or other organic materials. The lead strips are positioned alternately with the X-ray transparent strips, preferably of wood, on the curvature of the arc of a circle of a radius consti-

tuted by radially projecting beams of X-rays from a target at a distance 25 to 30 inches from the surface of the grid. This arrangement allows only those X-rays that are emanated directly from the target to pass through the grid—X-rays from sources in other directions than the target being completely eliminated from the radiographic field by their absorption at the lead strips.

During exposure, the grid moves approximately three to five inches sideways, admitting through largely those radiations that are incident perpendicularly to its curvature. In order to derive the full advantage from a Bucky diaphragm, its movement must be adjusted to correspond with the exposure time; the target must be positioned within the limits of the center of curvature of the grid surface (between 25 to 30 inches), and must be so aligned that the principal ray from the anode falls to the center of the exposure field and the diaphragm superimposed. Failure to observe these simple procedures results in the appearance of grid markings in the radiograph. For instance, if the entire exposure field of the radiograph suffers from grid markings, then the cause is attributed to the irregularity of grid movement; if the markings are present in the center or are included about the border area of the image, the condition indicates an incorrect distancing of the X-ray tube from the film; and, the improper alignment of the X-ray tube in respect with the Bucky diaphragm entails the appearance of grid lines on one side of the exposure field.

In the case of thick wooden X-ray table tops, the scattered radiation returned to the film is sufficiently large as to warrant the incorporation of a sheet of lead in the back of the exposure holder to eliminate this effect. Film cassettes contain a heavier sheet of the metal because of the extent of the incident radiation quality pertinent of the technic used.

In the following diagrams illustrating the general scheme of a Bucky diaphragm construction, Fig. 144 represents a flat grid having the same



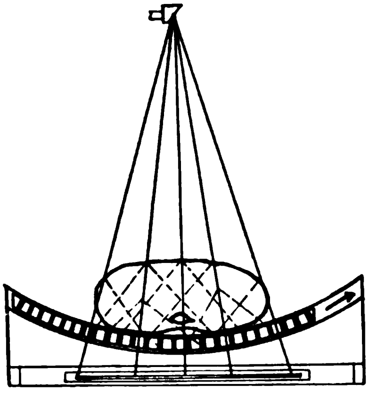


FIG. 144. DIAPHRAGM WITH FLAT GRID. FIG. 145. DIAPHRAGM WITH CURVED GRID.

radius of curvature as that of the curved grid shown in Fig. 145.

While the Potter-Bucky diaphragm reduces the major portion of the X-ray radiation emanating from the anode through the elimination of the

secondary rays, and further absorption of the beam by the lead strips in the grid, the useful energy reaching the radiographic film is consequently reduced. Approximately 70 percent of the primary rays is thus absorbed by the diaphragm. In order to compensate for this loss, the radiographic exposure should be prolonged from 3 to 4 times longer than for that required without the use of a diaphragm. Therefore, the exposure time for a radiographic technic using no diaphragm should be multiplied by 3.5 if it is desired to use a Bucky diaphragm in the technic.

For radiographs requiring both rapid exposure and elimination of scattered radiation, high-speed Potter-Bucky diaphragms permitting exposures as short as 1/20 second and as long as 10 seconds have been developed. Such a diaphragm is especially adaptable to the radiography of the chest, gall-bladder, gastro-intestinal tract, and genito-urinary tract.

Another method for eliminating the major portion of scattered radiation from the film is the use of a *Lysholm grid.* The device consists of very thin and narrow lead strips spaced closely together to form an extremely thin, flat grid, which functions while stationary; and, in use, it is placed between the patient and the film. The images of the lead strips are recorded in the radiograph, but owing to the fineness of the pattern, the use of this type of grid is not seriously objectionable especially for cases where a Potter-Bucky diaphragm may not be applicable, as in bedside radiography.

(*b*) *Characteristic Radiations.*—When a beam of primary radiation is incident upon metal parts of the X-ray apparatus an emission of secondary radiation having a quality independent of the incident beam is observed. The wave-length of this type of emission depends on the atomic number, or, more precisely, on the threshold or quantum frequency f_o of the metal radiated; and, therefore, the quality of the radiation is said to be characteristic of, and strictly dependent on, the secondary emitter. Metals having atomic weights greater than that of Aluminum are principal sources of characteristic secondary radiations. But, before a metal emits a characteristic (also called fluorescent) radiation, the inciting primary X-ray beam must possess a frequency f equal or greater than the threshold frequency f_o of the emitting metal. That is, the quantum energy hf of the primary radiation must be equal to or greater than the secondary quantum energy hf_o ($hf > hf_o$) in order that a secondary quantum emission may be realized. Accordingly, an X-ray photon having a wave-length, for instance, 1.5 Angstrom units can not incite a characteristic quantum radiation of 1.51 Angstrom units, for the energy hf of the former photon is less than that hf_o of the second. The characteristic radiations (even from the heaviest metal) being of low penetrating quality are largely absorbed by the exposure holder or the cassette. Thus, a radiation of this character is of little concern in radiographic work.

The use of filters aids, to a great extent, in the elimination of characteristic and long wave soft X-rays, which, otherwise, would interfere with the attainment of a sharp, well-defined radiograph. When using filters of sheet Aluminum of 1 mm thickness, the radiographic exposure time should be increased about forty percent.

5. X-Ray Measurements.—The quantity of X-rays generated at the target of an X-ray tube varies directly with the number of electrons im-

pinging on the target per second, and hence with the milliamperage across the tube, with the character of the target material, and with the square of the voltage. While the milliamperage across the tube affects the quantity of the X-rays produced, the voltage affects both the quantity and the penetrating quality of the radiation. Hence, the wave-length of the emission varies inversely as the voltage impressed on the X-ray tube.

(a) *Measurement of X-ray Intensity (Quantity)*.—As mentioned above, the quantity of X-ray output from an X-ray tube is a function of the tube current and the tension. Under most favorable conditions the quality of radiation from the target of high atomic weight in an ordinary diagnostic X-ray tube amounts to about 0.2 percent of the total energy applied to the tube. From both empirical relations and observations based on actual experimental results it is concluded that the yield or the intensity of X-rays is approximately proportional (in the optimum case where the characteristic radiation from the target and the wave-lengths of continuous spectrum are superimposed) to the square of the tension, and the efficiency of the yield further depends upon the atomic number of the target metal.

From above inferences it would seem that if an X-ray tube is energized with voltages in the neighborhood of a million volts or over the X-ray yield will markedly be improved. But, the increased voltage will so raise the penetrating quality of the radiation that when the beam is made incident upon matter it will traverse the latter without being absorbed to an appreciable degree. Consequently, such a quality in deep therapy work will have little value, and therefore, tubes energized by voltages of the order of 200 to 400 kilovolts are generally used for this purpose.

An equation formulated by Bouwers* through results grown from observations on the bolometer measurements of X-ray energy in absolute values is represented in the following convenient expression associated with X-ray output:

$$X_o = 5.6 \times 10^{-10} NV \tag{118}$$

where N is the atomic number of the target metal, and V the applied potential in volts. The expression has its limitations and does not hold for conditions other than specified above, and therefore, it should be used with reservations.

If equation (118) is divided by 100, the output energy X_o may be expressed in percent emission in respect to power input. Then, we obtain

$$X_{o.p.} = 5.6 \times 10^{-8} NV \tag{119}$$

in which $X_{o.p.}$ is the percentage output of X-rays by the impressed voltage V.

Example:—What will be the percentage of X-ray emission if an effective voltage of 50,000 volts is applied on an X-ray tube having a Tungsten target? The atomic number of Tungsten is 74.

From equation (119), we have

$$X_{o.p.} = 5.6 \times 10^{-8} NV \qquad \text{where,} \quad \begin{aligned} N &= 74 \\ V &= 50{,}000 \text{ volts.} \end{aligned}$$

*A. Bouwers, Measurement of the Intensity of X-Rays, Physica 5, 8, 1925.

$$X_{o.p.} = 5.6 \times 10^{-8} \times 74 \times 50{,}000$$
$$= .2072 \text{ per cent.} \quad \textit{Ans.}$$

Since X-rays cause ionization in a gas which they traverse, advantage is had in utilizing this property in the quantitative measurement of the X-ray intensity by employing an ionization chamber. A simple ionization chamber, shown in Fig. 146, consists of a cylindrical metal box C several centimeters long and about one centimeter or so in diameter, and having a metal plate P extending axially within the cylinder and well-insulated from the latter at S. At one end of the tube is a window W covered with a thin sheet of Aluminum or Mica and serves as a port of entry of the

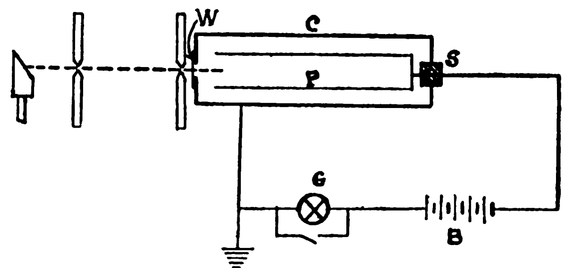


FIG. 146. X-RAY INTENSITY MEASUREMENT BY IONIZATION CHAMBER METHOD

X-ray beam whose intensity is to be measured. An electric field of about 250 to 300 volts per centimeter is maintained, from a battery B, between the plate and the walls of the chamber. When X-rays are made to pass into the chamber the plate acquires a charge, the rate and the magnitude of which per unit volume of air at standard conditions in the chamber is determined by an electrometer, or by a sensitive galvanometer G; and therefore, this charge is a measure of the intensity of the X-ray beam at a specified distance from the X-ray target.

Many commercial instruments have been devised for X-ray intensity measurements. Most common of these are the X-ray dosimeters especially used in measuring X-ray dosages in therapy work. Among these are the *Victoreen Iometer,* and the *Mecapion.* The latter is an integrating dosimeter utilizing both the radiation given off from the X-ray tube and the secondary rays, avoiding wall effect, and is independent of the wavelengths included in the X-ray beam. The instrument affords the measurement of X-ray dosages in roentgen units. A roentgen unit, denoted by r, is defined as that unit of quantity of X-radiation which, when both the primary and the deflected (secondary) radiations are utilized, produces in 1 Cc of air at standard conditions (760 mm mercury pressure and at 0°C) one electrostatic unit of charge, or 1/3000 microcoulomb. Thus an X-ray beam of unit intensity will produce an ionization current i of 3.33 x 10^{-10} *ampere* per cubic centimeter of air in the ionization chamber. A unit ionization current i is, therefore, equal to one r per second. Since an electrical quantity of such small magnitude can not be directly determined by ordinary electric measuring means, a three-element thermionic valve

tube is used to first amplify these minute current impulses before they can be recorded by a pre-calibrated meter connected in the circuit. Further information as regards to dosage measurements will be found in the section on Roentgen Therapy.

(*b*) *Measurement of X-ray Wave-Lengths* (*Quality*).—Following Laue's discovery of diffraction of X-rays by the cleavage planes of crystals, the first practical and reasonably accurate X-ray spectrometer was developed by W.H. and W.L. Bragg. The instrument fundamentally affords the measurement of angles between the cleavage surface of a crystal and the incident X-ray beam, in conjunction with an ionization chamber so placed as to determine the position and the intensity of the reflected, or the

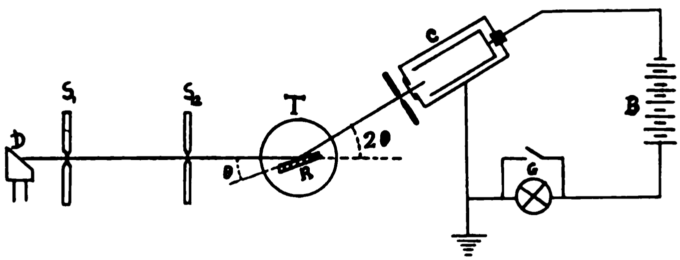


FIG. 147. SCHEMATIC DIAGRAM OF THE X-RAY SPECTROMETER.

emergent, rays (as the case may be, if the X-ray beam is normally incident on the crystal surface) upon the actuation of the electrometer in consequence of the trapping of the beam. The essential working parts of an X-ray spectrometer of the Bragg type is illustrated in the diagram shown in Fig. 147.

A beam of X-rays, incited by about 45 kilovolts, from the anode D, is collimated by slits S_1 and S_2 into a fine pencil, and allowed to fall at a glancing angle upon a crystal R, such as Rock Salt, or Calcite, mounted on a rotating table T. The reflected, or, the emergent, beam is made to enter the ionization chamber C, which is impressed with a high potential from the battery B. The chamber is also mounted on a rotating table (not shown in the figure) so that it can be rotated radially to the axis of the crystal during the locating of the beam of X-rays reflected from the crystal. Since the reflected beam makes an angle 2θ in respect with the incident beam, and knowing the distance d between the two given *cleavage planes* (grating space) of the crystal, the wave-length of the incident radiation may be computed by Bragg's formula

$$\lambda = \frac{2d.\ \sin.\ \theta}{n} \tag{120}$$

where θ is the angle between the incident X-ray beam and the crystal cleavage plane, and n stands for the spectral order of the wave-lengths.

The numerical value of d for Rock Salt is given as 2,814 X-units (1 X-unit = 10^{-3} A.U.). Therefore, if an X-ray beam becomes incident upon

the crystal at a glancing angle, for instance, 7° 15′, the wave-length of the radiation for the first spectral order will be

$$\lambda = \frac{2 \times 2{,}814 \times \sin 7^\circ\, 15'}{1}$$

$$= 2 \times 2{,}814 \times .1262$$

$$= 710 \text{ X-units, or } 0.71 \text{ A.U. } \textit{Ans.}$$

Due to the thermal expansion of the crystal, the grating space d of the crystal, in the above calculation, is specifically taken for observations made at 18°C. Another correction factor, which is not taken into consideration, arises due to the slight refraction of the X-ray beam as it passes through the crystal, in case the radiation is normally incident on its surface.

For X-rays incited by voltages anywhere below 65 or 70 kilovolts (effective) the radiation is usually made to fall at glancing angles to the surface of the crystal, while for higher kilovoltages than those given above, the X-ray beam is allowed to become incident normally with the cleavage plane of the crystal structure.

6. Absorption of X-rays.—Mention was made in the foregoing discussions that the *relative opacity* of different substances to X-rays is dependent on the *density*, the *thickness*, and the *atomic weight* of the material placed in the path of the radiation beam. Since, the radiation from the target of an X-ray tube is of *heterogeneous quality* (having many wave-lengths), it has been the common practice both in radiography and therapy to alter the quality of the primary radiation by inserting, underneath the tube, a sheet of Aluminum, Copper, or Tin, depending on the character of quality desired. Obviously the purpose of employing the metal sheet is to filter out the long-wave, or soft, radiations from the exposure field. It is further apparent that the softer the radiation the easier it is absorbed by matter. In order to arrive, therefore, to a deduction as to what extent the radiation intensity is decreased in passing through any given material, it will be expedient to derive a mathematical relation in order that an exact computation of the emergent intensity can be realized.

The diminution in the *intensity* of the *emergent X-ray beam* may be calculated when the intensity of the incident beam, and the *thickness* and the *coefficient of absorption* of the absorbing material are all known. For a given slab of thickness X, shown in Fig. 148, assuming that a beam of X-rays of intensity I_o, as it passes through the slab, diminishes in intensity to I. If we denote the magnitude of this diminution per centimeter path by μ, then the extent of the decrease in the intensity of the beam in traversing the increment dx will

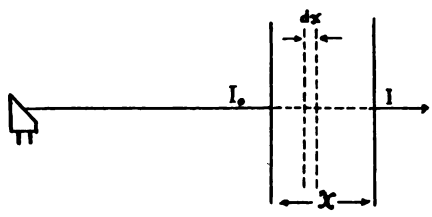


FIG. 148. DIMINUTION OF THE RADIATION INTENSITY OF X-RAYS IN PASSING THROUGH MATTER

be $\mu.dx$. The intensity I_o will then be reduced by $I_o.\mu dx$, or $dI_o = I_o.\mu dx$. Since the change in intensity occurs in the reverse direction to the incident beam, we are justified in designating the diminution by a minus sign. Hence, the quantity may be represented as

$$dI_0 = -I_0\mu dx$$

and,

$$\frac{dI_0}{I_0} = -\mu dx \tag{121a}$$

Integrating equation (121a) from one plane A of the slab to the other, B, we obtain

$$\int_{I_0}^{I} \frac{dI_0}{I_0} = -\int_0^X \mu dx$$

When the thickness X of the slab is equal to zero, then $I = I_o$; and, we may equate

$$\log \text{nat. } I = -\mu X + \log \text{nat. } I_0$$

$$\log \frac{I}{I_0} = -\mu X$$

and,

$$\frac{I}{I_0} = \epsilon^{-\mu x}$$

or,

$$I = I_0 \epsilon^{-\mu x} \tag{121b}$$

where ε stands for the Natural or Napierian base of logarithms, and numerically is equal to 2.7183, and μ is known as the coefficient of absorption of the material.

Frequently it becomes desirable to express the right-hand side of the equation (121b) in terms of the mass absorption coefficient of the material. This quantity is obtained by dividing the coefficient of linear absorption μ by the density ρ of the material. Then, we have

$$I = I_0 \epsilon^{-\frac{\mu}{\rho}.\rho x} \tag{122}$$

where $\frac{\mu}{\rho}$ is the mass absorption coefficient, or the degree of absorption of X-rays per cubic centimeter of the absorbing substance.

The intensity of a particular wave-length may be easily computed by means of the well-known *inverse square law,* which, when applied to X-rays, states that the intensity I_0 of X-radiation is directly proportional to the current and to the square of the kilovoltage applied on the tube, and inversely proportional to the square of the distance. Expressing this in an equation form, we have

$$I_0 = K\frac{V^2 i}{d^2} \tag{123}$$

in which, i is the tube current in amperes at a potential V in volts, d is the distance between the tube target and a particular point where the intensity of the uninterrupted beam is observed, and K is a quantity characteristic of the target material.

Table VIII gives the X-ray mass absorption coefficients of different materials for various wave-lengths of the incident ray (calculated by S. J. M. Allen).

Table VIII:—X-Ray Mass Absorption Coefficients.

X-Ray Wave-Lengths in A.U.	.0200	.081	.102	.151	.209	.240	.320
Carbon	.0582	.143	.150	.153	.166	.170	.200
Aluminum	.0559	.145	.169	......	.295	.356	.630
Iron	.0549	.235	.280	.595	1.260	1.750	3.950
Copper	.0542	.270	.335	.780	1.710	2.500	5.250
Silver	......	.740	1.170	2.650	6.500	9.600	21.100
Tin	.0544	.800	1.200	3.150	6.950	10.800	22.000
Tungsten	.0627	2.400	3.500	8.000	3.930	5.100	10.100
Lead	.0672	2.530	3.900	2.450	5.350	7.400	16.200

To further elucidate equation (122), let us take the following example:—

What percentage of the X-rays of wave-length 0.209 A.U. will be absorbed in passing through a slab of iron 0.8 centimeter thick? The density of iron is taken as 7.8.

According to equation (122), the intensity of the emergent X-rays from the slab will be given as

$$I = I_0 \epsilon^{-\frac{\mu}{\rho}\cdot\rho x} \quad \text{where,} \quad \begin{aligned} I_0 &= \text{unity, or } 100\%. \\ X &= .8 \text{ centimeter.} \\ \frac{\mu}{\rho} &= 1.26 \text{ gm/sq. cm.} \end{aligned}$$

The numerical value of $\frac{\mu}{\rho}\cdot\rho x = 1.26 \text{ x } 7.8 \text{ x } .8 = 7.862.$

$$
\begin{aligned}
\log I &= \log I_0 + (-7.862)\log \epsilon \\
&= \log 100 + (-7.862)\log 2.7183 \\
&= 2 + (-7.862 \times .43428) \\
&= 2 - 3.4139 = -1.4139 \\
I &= \text{Antilog}\ (-1.4139) = .259 \text{ per cent.}
\end{aligned}
$$

The percentage of diminution of the X-ray intensity in traversing the slab, then, is

$$100 - .259 = 99.741 \text{ per cent.} \qquad \textit{Ans.}$$

From the above illustrative problem it is obvious, then, that theoretically an absolute shielding of the X-ray intensity by increasing the thickness of a given slab is impossible. But, for practical purpose, a decrease in intensity, or the X-ray absorption, to the extent of 99.998 percent or more should be considered as perfect absorption in respect to the scope of our present study.

We should now be in a position to understand that the phenomenon of absorption of X-ray radiation is due to atomic energy transformations. Direct confirmation of the effect is realized in the emission of photoelectrons with various energies characteristic of the various inner shells of the absorbing atom when a beam of X-rays is incident on it. In converse process to the production of X-ray quanta as a result of electron bombardment of the atom, the absorption of X-rays by a metallic substance is accompanied by the ejection of photoelectrons whose velocities are dependent upon the quantum shells from which the individual electrons are derived. For instance, a photoelectron liberated from a *K-shell* will have a smaller velocity than the one dispelled by the same energy from an *L-level*. This is because it will take a greater amount of the quantum energy hf to remove an electron from the *K-level* than from an *L-level*. Accordingly, no transfer of X-ray energy will occur unless the radiation energy hf exceeds the quantum energy of the electron resident in a particular shell. To elucidate this further, if the characteristic radiation energives hf_k and hf_L are emitted respectively from the K and L *levels* of an atom as a result of electron impact, to reverse the process, the radiation energy must be either equal to or greater than the quantum energy of the electron in the respective shell. Therefore, X-ray radiations having frequencies less than f_k, f_L, f_m, etc., will not be absorbed by the respective levels but possibly by the next outer levels or other outermost levels. In an alternative case, the energy will be scattered or diffused.

QUESTION ON CHAPTER XV

1. (a) Give a brief account of the early knowledge of electrical phenomena leading to the discovery of X-rays.
   (b) What are X-rays? What properties do they possess that make them of diagnostic value?
   (c) How are X-rays produced? On what factors is the penetrating quality of the radiation dependent?
   (d) Of what practical importance are the differences in energy of quantum levels in the production of soft, or hard X-rays?
2. (a) Find the maximum frequency of an X-ray photon incited by a potential of 50,000 volts. Also, find the wave-length of the radiation in A.U.
   (b) What are secondary radiations? What sources give rise to secondary radiations?
   (c) Of what importance is a knowledge of secondary radiations in radiography?
   (d) The primary X-ray photon from the tungsten focus of an X-ray tube incites a secondary photon from the inside surface of a cone lined with a thin sheet of tungsten. How are the energies and the penetration qualities of the two photons compared? Explain fully.
3. (a) What properties of a Potter-Bucky diaphragm make it useful as an effective means of precluding the secondary radiations from the film?
   (b) What are filters? For what purpose are they used?
   (c) On what factors is the quantity of X-rays generated at the target dependent?
   (d) Compute the percentage of X-ray emission from a target having an atomic number of 78 and impressed with a potential of 60 Kv.P.
   (e) Discuss the method of measuring the intensity of an X-ray beam.
4. (a) How many roentgens will produce an ionization current of 36.63×10^{-10} ampere in 2.75 Cc of air in the ionization chamber?
   (b) Determine the wave-length for the second spectral order of an X-ray beam incident on the surface of calcite at an angle of 6° 20′. The grating space for calcite is given as 3.0 A.U.
   (c) What inherent properties of a substance are a function of its relative opacity to X-rays?
   (d) A beam of X-rays incited by 50-KV and 100 M.A. becomes incident on a 3 mm sheet iron placed 20 cms from the target (for which K is assumed to be unity). Determine the intensity of the emergent beam.
   (e) Compare the quantum energies and velocities of photoelectrons (produced by X-rays) from K-level and L-level.

CHAPTER XVI

ROENTGENOGRAPHIC EXPOSURE FACTORS

We have already seen that the quantity of X-rays produced in an X-ray tube is dependent upon the milliamperage across the tube, the impressed voltage, and the target material. It is also noted that the radiation output of a given X-ray tube having Tungsten for its target varies directly as the square of the impressed voltage. Two tubes (electron type) of essentially the same electrical and mechanical characteristics should, therefore, produce the same X-ray output under identical voltage and current conditions. This is not, however, strictly true in common practice, for, two tubes, identically same in constructional detail and load capacity, are not usually operated on the same machine and under same conditions. Owing to the fact that differences in the settings of the two different machines—one employing an auto-transformer to control the primary power input, while the other accomplishing this by means of a rheostat, or by the combination of the two devices—the wave form of the voltage and the current through the tube will be influenced to a slight degree and hence the X-ray output from either tube.

Other complications arising from the electrical conditions under which the X-ray tube operates, whether it is connected on a mechanically rectified machine, or on a half-wave or full-wave valve tube rectification system, all introduce minor differences in the tube load, and, therefore, have bearing on the radiation output of the X-ray tube. For all practical purposes, however, it will not be infeasible to expect the same efficiency from two different X-ray tubes of same make, type, rating and mechanical construction, as manufacturers of X-ray tubes are constantly improving the design and accuracy in the assembly of the tubes in an attempt toward attaining a uniformity in the output from all X-ray tubes having the same electrical and mechanical characteristics; and, modern X-ray tubes of reputable competitive firms meet with these descriptions quite satisfactorily.

In considering two X-ray tubes of different inherent characteristics, of course, variations in output which is occasionally observed may be due to the difference in the design and hence increased stem radiation in one tube in respect to the other, warping or pitting of the target in either tube, differences in target angle, and spacing between the cathode and the anode, and variations in the nature and thickness of the glass envelope.

In the accompanying discussions, however, we shall confine our consideration to the radiation from any given X-ray tube, irrespective of its mechanical characteristics, and will attempt to generalize the application of radiation-limiting devices external to the X-ray tube and of the controlling electrical factors. Obviously such externally-inserted devices in the path of the primary beam will inherently have the same con-

stant characteristics irrespective of the type of X-ray tube used on the machine.

1. The Radiographic Density A Function Of X-Radiation Reaching The Film.—The amount of X-ray energy absorbed by the sensitized surface of the film determines the radiographic density of the image. While the production of this energy from the X-ray tube varies as the square of the voltage applied, its absorption in the film varies inversely as the cube of the voltage or directly as the cube of the wave-length of the radiation. Moreover, insertion, in the path of the radiation beam, of the object (patient) and radiation-controlling devices such as the filters, diaphragm, etc., further impose limitations to the quality of the X-rays reaching the film. The following are some of the essential factors influencing the amount and the intensity of the X-radiation reaching the radiosensitive emulsion of the film:

(1) The impressed voltage on the cathode stream.
(2) Milliamperage sent through the tube (quantity of Cathode Rays).
(3) The nature of the focal spot material.
(4) The wave-length and hence the quality of the resultant X-rays.
(5) The focal-film distance (The intensity of X-rays varies inversely as the square of the distance).
(6) The extent of the decrease in the intensity of the X-ray radiation in its passage through the filter, the object (patient) radiographed, and the Potter-Bucky diaphragm.
(7) The use of the intensifying screens, or the cardboard exposure holders.
(8) The duration of the X-ray radiation, or the exposure time.

Of the above factors, the voltage, milliamperage, focal-film distance, and the duration of exposure are variable, and therefore, we can now formulate an equation by which the relations of the different entities may be expressed quantitively as shown below.

$$\text{Radiographic Intensity } (I) = \frac{Kv.P.^x \times M.A. \times T}{D^2} = \text{Radiographic Density.} \qquad (124)$$

in which, the superscript "x" stands (with limitations) for the square of the impressed kilovoltage, M.A. is the milliamperage across the tube, T stands for the time of exposure in seconds, and D is the focal-film distance given in inches.

If it is desired to obtain the same degree of radiographic density in a different exposure technic, the resultant value of the above quantities should be kept constant. That is, the result of the product of the $Kv.P.^x$, M.A., and Seconds divided by the D^2, of the second technic, should be numerically equal to the resultant radiographic energy value of the first technic. For instance: With a certain exposure technic of 50 Kv.P., 20 M.A., 5 Seconds, and 25 Inches, a good radiographic density is obtained; but, due to the magnitude of the distortion (enlargement) thus produced, the focal-film distance is increased to 30 inches, which change necessitates a corresponding increase in the exposure time. Thus, equating the two radiographic energy relations together, we have

Radiographic Density of 1st Technic = Radiographic Density of 2nd Technic.

or, $$\frac{(50)^x \times 20 \times 5}{(25)^2} = \frac{(50)^x \times 20 \times X}{(30)^2} \qquad [\text{where, } Kv.P.^x = Kv.P.^2$$

and $$X = \frac{5 \times (30)^2}{(25)^2} = 7.2 \text{ seconds.} \qquad \textit{Ans.}$$

We can approach this problem in the light of differences of radiation intensities produced at the film by 25-inch target-film distance and by 30-inch distance. For the first case (a), the intensity at the film, according to equation (124), will be

(a) $$\text{Radiation Intensity } (I_1) = \frac{(50)^2 \times 20 \times 5}{(25)^2}$$

$$= \frac{250{,}000}{625}$$

$$= 400 \text{ units (arbitrary)}$$

and, for the second case (b), we have

(b) $$\text{Radiation Intensity } (I_2) = \frac{(50)^2 \times 20 \times 5}{(30)^2}$$

$$= \frac{250{,}000}{900}$$

$$= 277.7 \text{ units (arbitrary)}$$

It is obvious from these two relations that the resultant radiation intensity at the film in technic (a) is greater than that of technic (b) by 122.3 arbitrary units, and hence, the ratio of the two intensities is

$$I_1 : I_2 :: 400 : 277.7$$

It is obvious from these two relations that the resultant radiation inten- in the case of the technic (b), by 400/277.7 in order that the film may receive the same amount of radiation energy. Thus, to find the exposure time in seconds for the second technic (b) we equate

$$\text{Exposure Time (b)} = 5 \times \frac{400}{277.7}$$

$$= \frac{2{,}000}{277.7} = 7.2 \text{ seconds.} \qquad \textit{Ans.}$$

which value exactly corresponds to that obtained above by use of formula (124).

In Fig. 149, assuming that a constant X-ray radiation is maintained from the target T to the screen A, 1 sq. cm. in area, and placed 20 cms. from the focal spot. The aperture H is so adjusted that X-rays, after passing through it, exactly cover the area enclosed by *abcd*. Since X-rays travel in straight lines in all directions, when the screen A is removed, the same radiation that covered the area *abcd* will now irradiate an area

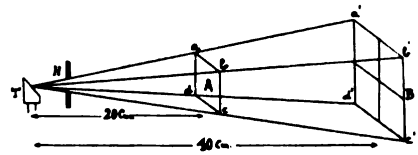


FIG. 149. DIVERGING OF THE X-RAY BEAM.

a′b′c′d′ at a distance B 40 cms from the target. But, the area of *a′b′c′d′* is four times that of *abcd* (that is, *a′b′c′d′* is 4 sq. cms). Thus, the same radiation that was restricted upon 1 sq. cm. area at A is now distributed over an area four times as large. (If a third screen was introduced at 60 cms from the target, the X-rays would cover an area nine times that at A). Accordingly, the intensity of the X-ray radiation on each square centimeter of the area *a′b′c′d′* will be 1/4th of that at *abcd*. But, since *a′b′c′d′* is located at a distance twice that occupied by *abcd*, we may now infere in a generalized statement that *"doubling the focal-film distance reduces the X-ray intensity to one-fourth, and tripling the focal-film distance will decrease the intensity to one-ninth, and so forth, of the original intensity limited to the first given area."*

If *a′b′c′d′* was replaced by a radiographic film, and the X-rays were made to fall on it, the intensity of the radiation at this location would be 1/4th of that at *abcd*. Therefore, by doubling the distance between the focal spot and the film, the radiation intensity is reduced to 1/4th; and conversely, by halving the focal-film distance, the intensity of X-rays is increased four times. Thus, it becomes now evident that the intensity of X-radiation varies inversely as the square of the distance from the target. This relation is generally known as the *Inverse Square Law*.

An equation representing the *Inverse Square Law* may be written as follows:

$$I = \frac{1}{d^2} \tag{125}$$

where, I stands for the intensity in terms of the arbitrary unit 1, and d is the distance between the source of radiation and the screen irradiated.

(*a*) *Distance-Time Relation.*—From the foregoing, it is noted that as the distance is increased the intensity of the radiation decreases. If a photographic film is placed at B, Fig. 149, the time of exposure must be increased four times of that as at A in order to produce at B the same radiographic density as at A.

Since, when the focal-film distance is doubled the intensity of the X-rays is reduced to 1/4th that of the original, it follows then that the time of exposure for the film at B must be increased four times that required at A

in order that the same radiographic density as at *A* may be realized at *B*. Assuming that the correct exposure time at *A* is 1.5 seconds, the exposure at *B*, which is twice as far from the focal spot as *A*, will then be 1.5 x 4 = 6 seconds. This relation may be put in the form of a rule, and expressed as follows:

Distance-Time Rule.—*The intensity of the X-ray radiation varies inversely as the square of the focal-film distance; hence, the time is directly proportional to the square of the distance.*

An equation to express the relation may be written as

$$\frac{T_1}{T_2}=\frac{D_1^2}{D_2^2} \tag{126}$$

or,

$$T_2=\frac{T_1D_2^2}{D_1^2} \tag{127}$$

in which, T_1 and D_1 are respectively the exposure time and the focal-film distance of the old technic, and T_2 and D_2 stand for the corresponding respective quantities in the new technic.

Example:—In a technic, the focal-film distance is 60 cms., and the exposure time is 4 seconds. If the distance is increased to 90 cms., what will be the new exposure time? What will be the exposure time if the distance is reduced to 30 cms.

From equation (127), we have

$$T_2=\frac{T_1D_2^2}{D_1^2} \qquad \text{where,} \quad \begin{aligned} T_1&=4 \text{ seconds.}\\ D_1&=60 \text{ centimeters.}\\ D_2&=90 \text{ centimeters.}\end{aligned}$$

$$T_2=\frac{4\times(90)^2}{(60)^2}=\frac{4\times 8100}{3600}$$

$$=9 \text{ seconds.} \qquad \textit{Ans.}$$

If the distance is reduced to 30 centimeters, the exposure time will be

$$T_2=\frac{4\times(30)^2}{(60)^2}$$

$$=\frac{3600}{3600}=1 \text{ second.} \qquad \textit{Ans.}$$

(*b*) *Milliamperage-Time Relation.*— Quite many radiographic technics applied to different parts of the object are expressed in terms of milliampere-second factor (written M.A.-S.), since the permissible amount of radiation to a given part within a specified period of time after the ex-

posure is limited by the magnitude of this quantity. For instance, one would not be justified in using the same M.A.-S. factor interchangeably for the head, or for arm, or for the thigh, because of the variance of the permissibility of radiation to these different parts, and of the differences in densities of the various tissues in these parts. Since, the radiographic density is primarily instituted by the milliamperage across the tube and the time of duration of the radiation, once the M.A.-S. factor for a given part of the body is established (through charts furnished by the manufacturer, or through experience) the kilovoltage furnishing penetration quality to the radiation beam may be determined by measuring the thickness of the object or part to be radiographed. The focal-film distance, however, may be adjusted in reference to the kilovoltage and to the amount of permissible enlargement in the resultant image.

The exposure time is an inverse function of the milliamperage, as given by the following rule:

Milliamperage-Second Rule:—*The milliamperage varies inversely as the time of exposure; hence, to change the milliamperage, the exposure time must be changed.*

Since the kilovoltage and the target-film distance remain constant, in this particular case, we may derive an expression from equation (124) to represent the relation of the milliamperage to the time of exposure. Thus, denoting each term by an appropriate subscript, we may write

$$\text{Rad. Density} = \frac{(Kv.P.)_1^2 \times M.A._1 \times T_1}{D_1^2} = \frac{(Kv.P.)_1^2 \times M.A._2 \times T_2}{D_1^2}$$

from which, cancelling all equal quantities from both sides of the equation, we obtain

$$M.A._1 \times T_1 = M.A._2 \times T_2 \tag{128}$$

and,

$$T_2 = \frac{M.A._1 \times T_1}{M.A._2} \tag{129}$$

or,

$$M.A._2 = \frac{M.A._1 \times T_1}{T_2} \tag{130}$$

in which, $M.A._1$ and T_1 are respectively the milliamperage and the exposure time of the first technic, and $M.A._2$ and T_2 are the respective quantities for the second technic.

Example:—In a technic, with 65 Kv.P., 100 M.A., 0.9 second, and 30 inches distance, a proper radiographic density is obtained. If the milliamperage is changed to 60 M.A., what should be the exposure time in order that the same radiographic density may be obtained?

From equation (129), we have

$$T_2 = \frac{M.A._1 \times T_1}{M.A._2} \qquad \text{where,} \qquad \begin{aligned} M.A._1 &= 100 \text{ milliamps.} \\ T_1 &= 0.9 \text{ seconds.} \\ M.A._2 &= 60 \text{ millamperes.} \end{aligned}$$

$$T_2 = \frac{100 \times 0.9}{60} = \frac{90}{60}$$

$$= 1.5 \text{ seconds.} \qquad \textit{Ans.}$$

In like manner, if the exposure time for the second technic was given as, for instance, 1.2 seconds, we could calculate the milliamperage necessary to secure the same radiographic density, by equation (130), which gives

$$M.A._2 = \frac{M.A._1 \times T_1}{T_2} \qquad \text{where,} \qquad \begin{aligned} M.A._1 &= 100 \text{ milliamps.} \\ T_1 &= 0.9 \text{ second.} \\ T_2 &= 1.2 \text{ seconds.} \end{aligned}$$

$$M.A._2 = \frac{100 \times 0.9}{1.2} = \frac{90}{1.2}$$

$$= 75 \text{ milliamperes.} \qquad \textit{Ans.}$$

(*c*) *Milliamperage-Distance Relation.*—Frequently it is particularly desired to reduce the distortion (enlargement) of the radiographic image to a minimum. This is usually accomplished by increasing the focal-film distance and correspondingly raising either the kilovoltage or the milliamperage of the X-ray tube. If the latter condition is met, we have the relation

$$\frac{M.A._1}{D_1^2} = \frac{M.A._2}{D_2^2} \tag{131}$$

in which the corresponding values of the terms are conserved.

Radiographing at an increased distance than that used for ordinary technics is especially desirable in the radiographing the chest, cervical vertebrae, lateral view of the skull together with, or without, a portion of the cervical region, etc., as the rays from the target are projected more parallel when the distance is large, and thus the resulting image undergoes a minimum enlargement.

Milliamperage-Distance Rule:—*The milliamperage is directly proportional to the square of the distance; hence, to change the distance the milliamperage must be changed.*

Example:—In a given technic, a proper radiographic density is secured with 40 milliamperes at a distance of 48 inches. What must the milliamperage be in order that the same density at a distance of 72 inches may be obtained?

From equation (131), we may write

$$M.A._2 = \frac{M.A._1 \times D_2^2}{D_1^2} \quad \text{where,} \quad \begin{aligned} M.A._1 &= 40 \text{ Millamps.} \\ D_2 &= 72 \text{ inches.} \\ D_1 &= 48 \text{ inches.} \end{aligned}$$

$$M.A._2 = \frac{40 \times (72)^2}{(48)^2} = \frac{207,360}{2304}$$

$$= 90 \text{ milliamperes.} \quad \textit{Ans.}$$

(*d*) *Kilovoltage-Distance Relation.*—Since the intensity of X-rays decreases as the focal-film distance is increased, sometimes it becomes more desirable to increase the impressed kilovoltage to compensate for the decrease in the radiation intensity.

Kilovoltage-Distance Rule:—*The square of the peak kilovoltage varies directly as the square of the focal-film distance.*

In an equation form, the above rule is represented as

$$\frac{(Kv.P.)_1^2}{D_1^2} = \frac{(Kv.P.)_2^2}{D_2^2} \tag{132}$$

or,

$$(Kv.P.)_2^2 = \frac{(Kv.P.)_1^2 \times D_2^2}{D_1^2} \tag{133}$$

where, $(\text{Kv.P.})_1$ and $(\text{Kv.P.})_2$ are respectively the kilovoltages of the old and the new technics.

Example:—In a technic, 60 Kv.P., 50 M.A., 3.5 seconds, and 30 inches, it is desired to change the distance to 48 inches yet keep the same radiographic density. How much should the Kv.P. be increased?

According to equation (133) we have

$$(Kv.P.)_2^2 = \frac{(Kv.P.)_1^2 \times D_2^2}{D_1^2} \quad \text{where,} \quad \begin{aligned} Kv.P._1 &= 60 \text{ kilovolts.} \\ D_1 &= 30 \text{ inches.} \\ D_2 &= 48 \text{ inches.} \end{aligned}$$

$$(Kv.P.)_2^2 = \frac{(60)^2 \times (48)^2}{(30)^2} = \frac{8294400}{900} = 9216$$

$$Kv.P._2 = \sqrt{9216} = 96 \text{ kilovolts. (final)}$$

$$96 - 60 = 36 \text{ kilovolts (change).} \quad \textit{Ans.}$$

(*e*) *Kilovoltage-Time Relation.*—It is gradually becoming a common practice to control the scale of gradation of a radiograph by properly chosen kilovoltage. The advantage of employing a higher kilovoltage in a technic, contrary to common conception, is in its offering an improved de-

finition and radiographic balance especially in parts consisting mostly of soft tissue. A higher kilovoltage also results in the reduction of the milliamperage and time, thus minimizing the chances of movement particularly in the organs of the body.

Table IX:—Kilovoltage-Time Relations.

To Reduce Exposure Time	Increase Kilovoltage With Double Screens	Increase Kilovoltage Without Screens
25%	7%	15%
50%	20%	40%
75%	50%	100%
To Increase Exposure Time	**Reduce Kilovoltage With Double Screens**	**Reduce Kilovoltage Without Screens**
25%	5%	10%
50%	10%	18%
75%	13%	25%
100%	16%	30%

When the kilovoltage is increased above that in a given technic the time of exposure is correspondingly decreased. Table IX, prepared by Eastman Kodak Company, provides with approximate corrections for determining the kilovoltage or the exposure time when a change in either one is desired.

Example:—In a technic, employing 65 Kv.P., 50 M.A., 6 seconds, and a 48 inch distance, with double screens, it is desired to obtain more penetration by increasing the tension to 70 kilovolts. What change in exposure time will incur?

The increase in the tension is 5 kilovolts which is approximately 7% of 65 Kv.P., and corresponds, according to Table IX, to a reduction of 25% in the exposure time, using double intensifying screens. Thus, the correct exposure time will be

$$25\% \times 6 = 1.5 \text{ seconds.}$$
$$6 - 1.5 = 4.5 \text{ seconds. Ans.}$$

In the above example, suppose it was necessary to use a 1.5-second time factor in order to reduce the chances of movement of the part radiographed. What change in the kilovoltage would be necessitated?

The change from 6 to 1.5 seconds in the exposure time corresponds to a reduction of 75%. We find in Table IX that a 75% reduction in the exposure time necessitates a 50% increase in the kilovoltage. Therefore, the new kilovoltage should be

$$50\% \times 65 = 32.5 \text{ kilovolts (change). Ans.}$$
or, $$65 + 32.5 = 97.5 \text{ kilovolts (final Kv.P.).}$$

2. Potter-Bucky Diaphragm Constant.—It is already noted that while the Potter-Bucky diaphragm is designed as an effective means for reducing the scattered radiation from the object radiographed, a considerable amount of the primary radiation is absorbed by the apparatus, thus necessitating a longer exposure in the technic. This absorption is quantitatively equivalent to a radiation energy of about 70 percent, and hence, in using a Bucky-diaphragm, the exposure time should be increased 3 to 4 times that required without the use of the diaphragm. Thus, the average absorption constant for the diaphragm will be 3.5, which may be expressed in an equation form as

$$T_2 = T_1 \times 3.5 \tag{134}$$

where T_2 represents the exposure time for the technic employing a Bucky diaphragm, and T_1 is that for the technic employing no diaphragm.

Example:—In a certain technic, using intensifying screens and no Bucky diaphragm, the exposure time factor is 4 seconds. In order to eliminate the major portion of the scattered radiation from the exposure field a Bucky-diaphragm is inserted. What will be the new exposure time factor?

According to equation (134), the new time will be

$$T_2 = T_1 \times 3.5 \qquad \text{where, } T_1 = 4 \text{ seconds.}$$

$$= 4 \times 3.5 = 14 \text{ seconds.} \qquad \textit{Ans.}$$

The inference that the time factor for the Potter-Bucky diaphragm varies from 3 to 4 is of direct concern to grid ratio, which ranges from *8-1* to *5-1*. A grid ratio implies that the wood strips incorporated between the lead strips of the grid are about *8* to *5* times as deep as they are wide. The *8-1* grid ratio is more effective for high kilovoltage technics, while the *5-1* (grid ratio for ordinary Bucky diaphragms) serves more satisfactorily in the lower kilovoltage ranges as employed in general radiographic procedures in medical work.

Another factor that is of concern in the use of a Potter-Bucky diaphragm is the increase in the object-film distance, which condition results in an increased enlargement of the image thereby lessening the sharpness of the radiographic detail to some extent. This drawback may be overcome almost entirely by increasing the target-film distance, and by essentially using the smallest focal-spot X-ray tube that will safely withstand the tube load for the particular exposure.

3. Intensifying Screens and Their Characteristics.—The energy absorbed by the emulsion of an X-ray film exposed to the direct radiation from the X-ray tube target amounts to about *1 percent* of the incident radiation energy, while the remaining *99 percent* passes through without being transformed. Since the degree of blackening of the gradations of the radiographic densities constituting the image is dependent upon the amount of absorption of X-rays by the sensitized surface of the film, a means for more fully utilizing the radiation passing untransformed through the film is characterized in the intensifying screen, which adds its fluorescent action, on the film emulsion, to the direct effects of the X-ray radiation.

The screen owes its intensifying characteristic to the fluorescent properties of certain chemicals, such as Zinc Sulphide, or Calcium Tungstate, which, when irradiated by X-rays, fluoresce with an intense characteristic visible radiation. The X-radiation energy absorbed by these salts is intensified considerably. Thus, when the fluorescent compound is applied to a surface and brought in close contact with the X-ray film, the photochemical effect in the emulsion of the film will be increased from eight to twenty times that without the use of the fluorescent material, as the latter will absorb X-rays and radiate visible light to the film.

Distinct advantage is had in employing Calcium Tungstate in present X-ray intensifying screens. Some of the most effective intensifying screens, such as offered by Eastman Ultra-Speed X-Ray Intensifying Screens, are made of this fluorescent compound. The crystalline chemical, after having been ground into a uniformly fine powder, is mixed with a suitable binder, and the resulting mixture is applied uniformly on one surface of a cardboard support, which is then called an intensifying screen. Two of such a screen, in turn, are mounted in a rigid holder, called a cassette, which, when loaded with a film, affords a uniform and substantial contact between

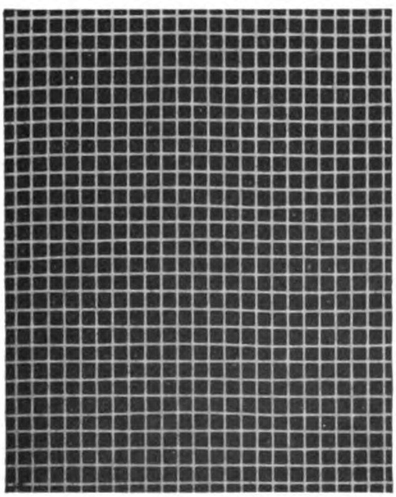


FIG. 150A. SHARP IMAGE DUE TO GOOD CONTACT.

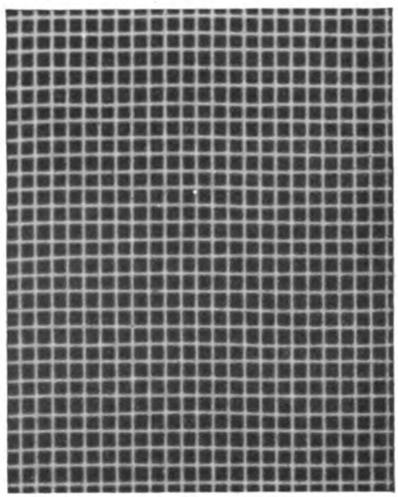


FIG. 150B. FUZZY IMAGE DUE TO POOR CONTACT.

the surfaces of the film and the screens. If the screens fail to make even contact with the emulsion of the film, the resulting radiograph will not be exempt of blurred image. A test for determining whether the screens are making the proper contact with the film may be performed by placing a wire screen on the top of a loaded cassette and making a flash exposure. If good contact is secured between the surfaces of the film and the screens, the image of the wire mesh will be outlined sharply, as shown in Fig. 150a; if the image is blurred and fuzzy, as shown in Fig. 150b, poor contact is indicated. When the latter is the case, the screens must then be padded with thin paper to obviate the cause.

Generally an effective screen, such as offered by Calcium Tungstate or Fluorazure[1], reduces the exposure time to 1/20th, or less, that required for direct exposures. Owing to the fact that, when screens are used, the radiographic image is mainly formed by the fluorescent light, which, being of the same character as visible light, does not traverse opaque bodies such as dust or dirt, the screens should be kept thoroughly clean in order that maximum advantage may be realized from them. Any marking on the screen, from inadvertent handling, may be removed by washing with soap and water, and then carefully dried with a piece of soft linen. Care should be exercised that the screen surface does not become scratched in so doing.

In case the Calcium Tungstate used for intensifying screens is contaminated with impurities, an appreciable persistence of phosphorescence due to the extraneous action of the compound will result. Consequently, radiographs produced in contact with this screen may present uncertain interpretations. Hence, utmost caution is observed to maintain purity during the manufacture of this compound.

The requisition of modern radiography is one of *"speed"* factor, which is made possible by intensifying screens. The speed of the screens may be directly influenced by the size of the crystals of the fluorescent material —the larger the crystals, the more abundant the fluorescent light, or the faster the screen; and, the smaller the crystals, the less fluorescent light is given off, and therefore, the slower the screen[2]. Eastman High-Definition Screens, which have small crystals, have a speed constant of *1/8* (8 times faster than cardboard exposure holder), but they produce the highest quality of sharpness in definition of the radiographic image. The prevalent purpose in view of these screens is, it is claimed, the provision of a "grainless screen which would record the most minute detail with exactitude," with speed as a secondary consideration.[3] In industrial radiography, how-

FIG. 151. LOADING A CASSETTE.

[1]Trade name for Zinc Sulphide screen coated with blue Azo-Dye (G.E. Co.).
[2,3]Arthur W. Fuchs, Radiography & Clinical Photography, pages 2-4, (June-1938) Eastman Kodak Company.

ever, metal screens are used to some extent to obtain the finer detail of the metallic grain of the specimen radiographed.

The fact that Calcium Tungstate screens are universally employed in almost all types of radiography, the standard X-ray film is so designed that its range of sensitivity to the wave-lengths of the blue-green fluorescence (about 3500-5000 A.U.) of the screen is far more prominent than to longer wave-lengths. The speed factors of these screens generally range from *1/6* to *1/20,* depending on the type of screen. That is, the screens essentially reduce the exposure time to *1/6th* to *1/20th* that required with direct exposures using cardboard holders.

Fig. 151 illustrates the manner of loading a double-intensifying-screen cassette. It will be observed that the black paper covering of the film is removed before the film is placed in the cassette, while with a cardboard holder, as in Fig. 152, the black paper is left on the film so as to provide added protection against visible light of any character.

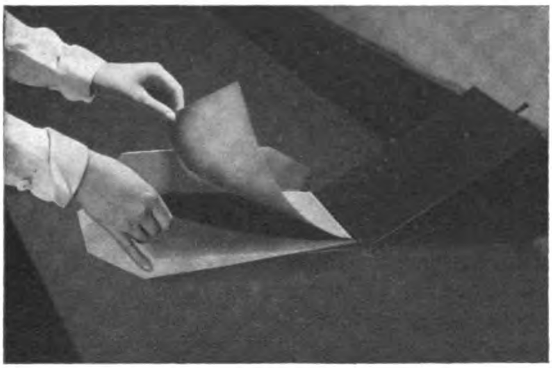


FIG. 152. LOADING A CARDBOARD EXPOSURE HOLDER.

4. Cones and Filters, and Their Time Factor Relations.—Frequently it becomes desirable to obtain the maximum definition in an image by eliminating extraneous secondary radiations from the field of exposure. This is accomplished by using a *ray-proof cone* which restricts the radiation to the area of exposure desired. A cone is essentially made of a material offering considerable opacity to X-rays, and eliminates the radiation from the surrounding structures of the exposure field. The material may be Iron, Steel, or either one lined with sheet lead having corrugations so that any possible deflection of rays from the cone are trapped in these grooves. Some manufacturers prefer to use lead-glass in the cone construction. Of these, Philips Metalix Corporation has developed lead-glass cones having various port dimensions so that various selections may be made for restricting the field of exposure (or the image) to the required area. Various cones of competitive make are shown in Fig 153.

When using cones, it is often necessary to insert a sheet of metal into the aperture of the cone receptacle right below the target of the X-ray tube.

This metal sheet is called a filter, since it filters out the unwanted X-ray radiations, and it is made of a selected metal having uniform density. Usually, metals used for filters are Aluminum, Copper, and Lead.

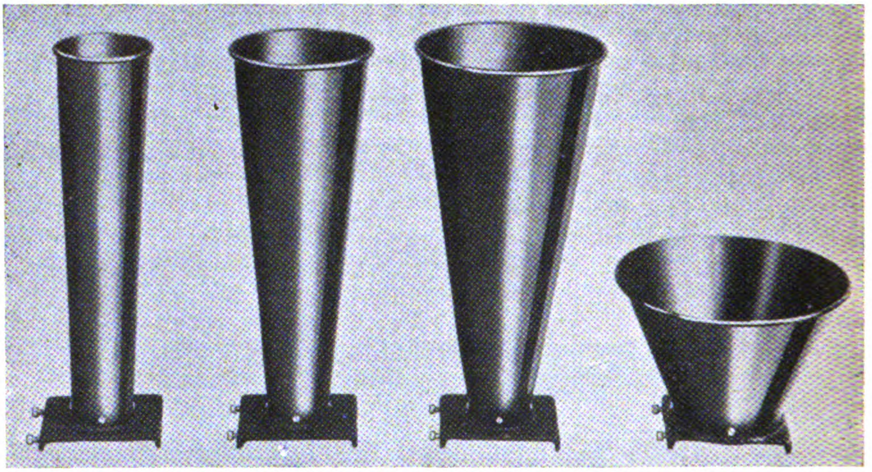


FIG. 153. EXAMPLES OF CONES OF VARIOUS SIZES. (G.E. X-RAY CORP.)

Experimental observations reveal that Aluminum offers more transparency for softer rays, while Copper for harder rays. The combination of proper thickness ratio, therefore, should provide a criterion whereby approximately same degree of absorption of the medium-hard rays may be realized with applicable feasibility. The arrangement is extensively used in measurements of X-ray intensities and permissible radiation dosages.

The use of a proper size cone furnished with a filter is especially recommended for dental radiography, and frequently, for general radiographic work. When the part irradiated is as close as 12 inches or less from the X-ray tube target the provision of a filter of appropriate thickness is indispensable so that soft radiations (long wave-length rays), which do not contribute to the production of the radiograph, are eliminated from the exposure field. The importance of this precaution can not be overemphasized especially for epicranial regions when exposed to unrestrained quantities of soft radiations, which then may be accompanied, within a few weeks after exposure, by the falling of the hair. Permanent partial baldness due to intermittent exposures to soft radiations has been reported. As the physiological action of X-rays is cumulative, exposure to the radiation should not exceed the amount permissible for the particular part, and that the process should not be repeated, on the same body area, for at least several weeks.

When using filters of sheet Aluminum, of 1 mm thickness, mounted in a cone, the radiographic exposure should be prolonged about 30 to 40 percent, for the metal decreases the radiation intensity to an appreciable extent.

From above discussions, it is apparent that for either radiographic or fluoroscopic work the inclusion of an Aluminum filter of a thickness between 0.5 to 1 mm, and permanently mounted at the port of radiation of the tube, becomes essential in the interest of safety to the patient.

QUESTIONS ON CHAPTER XVI

1. (a) State the electrical and physical conditions that have bearing on the radiation output of an X-ray tube.
   (b) State the essential factors determining the radiographic density of an image.
   (c) What relation has roentgen ray intensity to radiographic density?
2. (a) In a technic with 52 Kv.P., 40 M.A., 5 seconds, and 30 inches, a proper radiographic density is obtained. Keeping the voltage, exposure time, and the focal-film distance constant, how much should the milliamperage be increased in order to double the radiation intensity? How much will the radiographic density increase?
   (b) A square lead plate placed 40 cms from the X-ray target is removed to a distance of 60 cms. What relative radiation intensity will reach the plate?
   (c) All other factors remaining constant, how much should the focal-film distance be decreased in order that the film may receive nine times the radiographic intensity as that received at the original distance?
3. (a) If the focal-film distance is increased one-fifth, how much should the time of exposure be increased, assuming that all other factors remain constant?
   (b) In a certain technic, the focal-film distance is 36 inches, and the exposure time is 4.4 seconds. At what focal-film distance could an exposure time of 2 seconds be used?
   (c) A technic of 60 Kv.P., 80 M.A., 1.6 seconds, and 30 inches gives a proper radiographic density. If the milliamperage is changed to 16 MA, what will be the time of exposure?
4. (a) To reduce distortion to a minimum, the focal-film distance is changed from 30 inches to 42 inches. How much should the milliamperage be increased for 42 inches, if proper radiographic density is obtained with 20 MA employed with the former distance technic?
   (b) In a technic, 54 Kv.P., 25 MA, 4.2 seconds, and 36 inches, it is desired to change the distance to 48 inches. How much should the Kv.P. be increased in order that the radiographic density may remain same?
   (c) In a certain technic employing double screens, it is desired to obtain more penetration by increasing the voltage from 55 Kv.P. to 66 Kv.P. Using Table IX, compute the change to incur in the original exposure time of 6.5 seconds.
5. (a) Account for the Potter-Bucky diaphragm constant. What is a grid ratio?
   (b) In a technic for pelvis, using intensifying screens, an exposure factor of 4.5 seconds is used. In order to eliminate the major portion of the secondary radiations from the exposure field, a Potter-Bucky diaphragm is used. What will be the new exposure time?
   (c) What are intensifying screens? What inherent properties render them valuable in radiography?

6. (a) A technic for the lateral view of a certain skull is given as 68 Kv.P., 20 MA., 1 second, and 30 inches, using double intensifying screens. In order to eliminate major part of the soft radiation from the patient's face a 1-mm Aluminum filter is inserted. To further eliminate the secondary radiations from the film, a Potter-Bucky diaphragm is used. How much should the time of exposure be increased?

   (b) In a certain technic, the focal-film distance is 72 inches, and the exposure time is 0.2 second. How much should the kilovoltage relative to the original tube tension be increased so that an exposure at 54 inches may be reduced to 0.1 second?

CHAPTER XVII

THE ROENTGENOGRAM

A roentgenogram is a shadow representation on a photographic film of the different densities of an object traversed by X-rays. It is constituted by the point by point recordings of the various X-ray intensities affecting the emulsion of the film. The variations of the X-ray intensities of the emergent beam reaching the film are dependent upon the differences in densities, thickness, and composition of the object traversed. In a radiograph, more radio-opaque parts are represented by lighter regions, whereas more radio-transparent parts by darker regions. A network of dark shadows uniformly distributed in a field of relatively lighter area represents cancellous tissue; a uniform more or less dark band of varying width or length included by lighter margins extending about this band as if sheaths of radio-opaque material represents a canal in long bones; cavities of various shapes, and sizes in bone structures, air sinuses, sockets in the joints, foramens, sutures, bone fractures, air-passages, air-cells, pus-pockets, ducts, blood vessels, interstitial regions, etc., are represented by darker shadows in contrast with that of the surrounding tissues. In fluoroscopy, the converse is true; more transparent parts are represented by lighter regions, and more opaque parts by darker regions.

The density of the exograph increases with increasing X-ray intensities, and the sharpness increases with increasing focus-object distance. Since the further the object from the source of X-rays the smaller the shadow it casts upon the screen in its immediate vicinity, the distortion in the resulting image diminishes in an important degree. Just as the shape of the shadow of an object differs materially from that of the object itself when intercepting the rays at an angle other than normal to its plane, the radiograph may suffer from excessive distortion due to improper alignment of the object in relation to the focal spot and the film. Close approximation of the object-film distance will markedly aid in producing the desired purpose.

Visualization of the radiograph may be aided by positioning the eye normally to the center of the image placed same distance apart from the eye as the focus-film distance used for the technic; and, the orientation of the radiograph may be secured by indicating the right and left sides of the radiograph by means of suitable lead markers fastened with a band on a corner of the exposure holder or cassette during exposures.

1. Roentgenographic Procedure.—In view of the fact that a radiograph is a shadow picture defining the different densities of the structures constituting the part radiographed, radiography has become indispensable in the detecting and locating the internal defects and conditions of the human body and of the industrial materials as well. In medical diagnosis the application of X-rays to the examination of the fractured bones, to locate bullets and swallowed objects, to study the condition and develop-

ment of involved structures such as of the lungs in incipient tuberculosis, of the gastric organ in its formation of ulcerous or cancerous tissue, of decaying teeth, of the cerebral region due to the differentiation of the brain cells during malignancy, of the hepatic organs, and of the organs in the abdominal and pelvic regions, has gained much in prominence. The use of the introduction of Bismuth. and Barium, salts in an emulsion or suspension form into the alimentary canals, and the injection of iodized oils into bronchial tubes or into the cystic ducts and the bladder of either the renal or of the hepatic organ, to produce opacity in these parts or to throw them into relief for affording the radiographic diagnosis, are widely known and applied in radiography.

In making a radiograph, the procedure to be followed and routinely adopted must be considered as prerequisite to performing every radiographic examination. A sequence of steps to be taken may be stated as follows:

1. *Determine the region, thickness, and the nature of the part to be radiographed.*
2. *Determine whether or not the use of a Potter-Bucky diaphragm, a cone, or a filter becomes necessary in the radiographing of the part.*
3. *Adjust the X-ray tube to such a distance from the film as to give the optimum definition with least amount of distortion (magnification).*
4. *Set the controls for the proper milliamperage-seconds and the kilovoltage to produce the desired radiographic density.*
5. *If sharpness in definition is desired, select the finest focal-spot tube that will safely withstand the load to be applied to the tube.*
6. *Position the patient properly so that the principal ray falls on the center of the area of exposure.*
7. *Attach identification markers to the exposure holder or the cassette and place it in correct relative position with the X-ray tube and the subject.*
8. *If necessary, use compression bands, or sand bags, to immobilize the patient.*
9. *Apply the power to make the exposure.*
10. *Remove the exposure holder or the cassette, treat the film in the processing solutions, wash, and set it aside to dry.*

Knowing the exact region of the part to be examined, it becomes further necessary to determine whether or not the use of a Potter-Bucky diaphragm is called for. It is advisable to always use a Bucky diaphragm whenever the part to be radiographed is thick, and secondary radiation from it is of certainty. Parts such as the *skull, thoracic organs, the abdomen,* and *pelvic regions usually are sources of scattered radiations,* and therefore, a Potter-Bucky diaphragm becomes indispensable in radiographing these regions. When using this apparatus, however, it is recommended to raise the kilovoltage slightly.

To eliminate the inclusion of the scattered radiation from the surrounding soft parts outside of the desired area of examination, the insertion of a proper size cone to restrict the primary radiation to just the desired area of exposure is of added advantage in insuring a sharp radiographic definition. Some radiographers consider the inclusion of a filter in every

radiographic procedure as optional. Nevertheless, when radiographing or fluoroscoping any part in the head region filters must invariably be used as a precaution against the deleterious effects that may result in the skin or in the scalp of the subject due to soft rays.

The electrical factors to produce the necessary quantity and quality of the X-ray radiation may be determined by measuring the thickness of the part to be radiographed and consulting the charts furnished by the manufacturer of the X-ray apparatus. If such charts are not available, trial exposures on an average person weighing between 150 to 160 pounds may be made until the correct density of the film is secured. Relative technics on other individuals may be determined in comparative relation with the technic already obtained on the average individual. Ordinarily, once the milliamperage-seconds for a given part under examination is known, the kilovoltage may be varied to provide the desired penetration quality. Too high a kilovoltage will impart a gray appearance to the radiograph, whereas too low a kilovoltage will produce excessive contrast, which is equally objectionable in the attainment of a well-balanced radiograph.

A sharp definition is practically desired in every radiograph, and to obtain this the part to be radiographed must be placed as close to the film as possible, and the target-film distance must be so adjusted as to insure maximum definition with least enlargement of the image. If the part to be radiographed is an extremity, the optimum definition will be realized by using a cardboard film holder. With this the outlines of the structures and especially the cancellous tissues will escape the effect of diffusion of the radiation or blurring otherwise would be due to the fluorescent crystals, if intensifying screens were used.

An average distance of 30 inches will be sufficient for radiographing the parts which do not contain structures far removed from the film. All extremity work may be performed at 25 inch distance by using a cardboard exposure holder for maximum definition, while other parts generally call for larger distances and hence for intensifying screens to reduce the radiographic effects due to involuntary movements of the visceral structures, by shortening the exposure time. Owing to the divergence of the X-ray radiation and hence the production of a decided magnification of the lung structures remotest from the film, greater target-film distances, between 56 to 72 inches, become more preferable. For maximum detail, it will be most advantageous to use an X-ray tube having the smallest focal spot that can safely withstand the power during the exposure period. For dental radiography, a target-subject distance of 12 inches, and the use of a filter of 1 mm Aluminum are recommended.

Next, position the patient in direct alignment with the target and the film so that the principal ray passes through the center of the exposure area and falls perpendicularly to the center of the film, being careful to note that identification markers are always attached to the film holder preliminary to the exposure. If necessary, immobilize the patient by using compression bands, or sand-bags. Immobilization may also be accomplished in a simple way by substantially placing the part to be radiographed on the table or on the exposure holder in such a manner as to enable the subject to hold that position with the least exertion of his effort.

Having gone through these preliminary preparations, the patient is advised to breathe quietly, or, as the case may be, to hold his breath during the entire exposure period. The X-ray tube is then energized by pressing the push-button until the timer automatically ends the exposure. The power is shut off from the apparatus and the tube stand is rotated sideways to allow the removal of the patient from the table. The film holder is taken to the dark room for the further treatment of the exposed film in the processing solutions. The process of development takes usually 5 minutes at an optimum temperature of 65° F, and the fixing of the film takes 10 minutes or over. If this development procedure is standardized, an accurate measure of the electrical factors required to produce the optimum radiographic effect may be acquired by studying the finished radiograph. (Further details on time-temperature technics are given in Chapter XVIII.)

A simple rule in studying the radiograph may be observed as follows: If the radiograph is unnecessarily dense and the image is partially obliterated from excessive blurring an over-exposure is indicated, and reducing the milliamperage or the exposure time at the next exposure will usually improve this condition; if the radiograph lacks the proper detail and contrast, and the parts are almost indistinguishable, an under-exposure is indicated, and the condition usually can be remedied, when making the next radiograph, by increasing either the milliamperage or the exposure time. In case the image is either gray or over-contrasty, the condition indicates respectively an over-penetration or low-penetration. For the first case, decrease the kilovoltage, while for the second increase the kilovoltage, for the next exposure of the same part.

In view of the fact that the exposure factors used on a given machine can not always be applied to another apparatus, due to differences in their rectification systems, to differences in installation parts, to the inclusion in one or the absence in the other of electrical devices materially affecting the readings of the electric meters, etc., it will be more advantageous for the radiographer to standardize a routine technic for various parts comparable to the conditions on his particular equipment. These findings may be recorded on suitable chart forms for routine use.

2. Radiographic Density.—When the radiographic film receives proper amount of X-ray energy so that the resulting image consists of a properly balanced shades of light and dark shadows, insuring a ready distinguishability of the cancellous tissues and other delicate tissue structures, the radiograph is said to have the proper density.

The density of a radiographic image depends upon the magnitude of the milliampere-seconds, and the quality of the X-ray wave-lengths. The higher the value of the milliampere-seconds and the higher the impressed potential (with limitations) the greater the radiographic energy absorbed by the emulsion of the film, and hence, a radiograph of increased density will be the result. Further dependence of the radiographic density on the target-film distance may be shown by equation (124), which gives

$$\text{Radiographic Density} = \frac{(Kv.P.)^2 \times M.A. \times T}{D^2}$$

in which, the density is shown to be inversely proportional to the square of the distance.

A glance at this expression at once will evince that any variation in any one of the factors on the right hand side of the equation will affect the radiographic density. All other factors remaining equal, increasing the distance between the X-ray tube and the film will decrease the density of the radiograph (See Chapter XVI). Thus to increase the density to any desired value any one of the factors in the numerator should be increased or the focus-film distance D must be correspondingly decreased; and, to decrease the density the converse of this is true. The focal-spot size, however, does not affect the density of the radiograph.

3. Radiographic Detail.—When the definition of the outlines of the recorded shadows in a radiographic image is sharp, clean-cut, and all the calcellous tissues of bone structures are well-defined, the radiograph is said to have good detail. The radiographic detail is constituted by the projected image of minute structural elements of the part radiographed.

The chief determinant in a radiograph for diagnostic purposes is the definition with which the radiographic detail is recorded. When desirable, a high quality of sharpness may be obtained by employing cardboard exposure holders, but the use of the latter is confined only to those parts that are thin and contain comparatively small amount of soft tissue that scattered radiation becomes a negligible factor. For thicker parts, which are a source of excessive secondary radiation, and hence the use of a Potter-Bucky diaphragm is indispensable, the time of exposure is necessarily to be lengthened, which procedure subjects the X-ray tube for an unnecessarily longer loading period. This disadvantage is obviated by the use of double-intensifying screens, which shorten the time of exposure considerably.

To secure the maximum detail, however, the fluorescent crystals of the screens should be as small and uniform in size as possible. When the latter case is conserved, the sharpness of definition increases with sacrifice in speed. That is, the smaller the fluorescent crystals the less abundant is the fluorescence from the screen, and hence the screen speed factor is low and the radiographic definition is high; if the crystals are larger, more fluorescent light will reach the film and hence the screen factor will be high (fast screen) but the definition of the radiograph produced with this screen will be comparatively poorer.

The above phenomena are further elucidated by diagrams in Fig. 154, in which the image of a single structural element of an object intercepting the beam of X-rays is projected past a screen and recorded on the film. If a single X-ray beam traverses a unit structure *A* and strikes a large crystal, as in (a), the crystal becomes a source of fluorescent light and radiates it in all directions. A portion of this light reaches the film at varying angles, and the sensitive emulsion becomes affected wherever the incident light penetrates. Only that portion of the fluorescent light that is incident almost normally to the emulsion of the film produces an image of sharp detail of the object element, while portions striking the film at angles other than these incidences become responsible for the unsharpness or blurring of the image. Owing to the large size of the fluorescent crystal,

the light from it will cover a larger area than the projected image of the unit structure, whereas in the case of a smaller crystal the divergent fluorescent light will only cover comparatively a small area, as shown in (b). Consequently, the detail of the projected image will have better definition. Obviously then it will be expedient to assume that the sharpest detail is only possible by crystals of infinite size, or, putting the statement in another form, by using no crystals. The last is illustrated by Figure c),

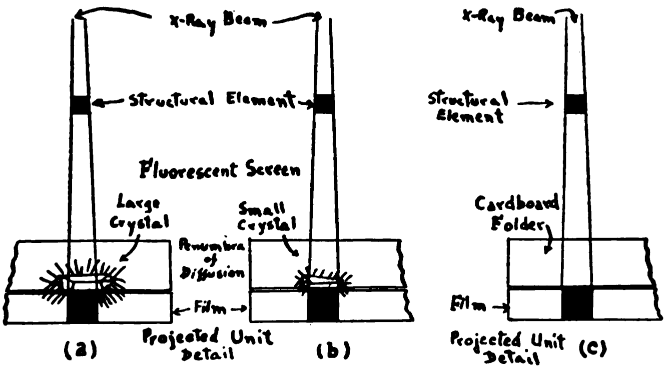


FIG. 154. COMPARISON OF DETAIL DELINEATIONS.

in which cardboard folder is substituted for intensifying screens, securing the highest quality of image definition. Unfortunately, the diminished speed by employing no-screen technic will preclude the use of cardboard holders for rapid radiography. The latter condition then limits the use of cardboard folders to thin parts, such as the extremities, and for thicker parts intensifying screens are indispensable even though a certain amount of detail sharpness is sacrificed in employing the latter.

With modern demand of high speed radiography combined with high definition in the detail has led the Eastman Kodak Laboratories to the development of High-Definition X-ray Intensifying Screens, which, when used with Eastman Ultra-Speed Films, reduce the time of exposure to 1/8 that required for No-Screen type film. It is further claimed that these screens have proved, in higher kilovoltage technic, "to be capable of recording the fine detail of any part with the most effective contrast," and the time of exposure becomes only twice that required for Eastman Ultra-Speed Screens.

The detail of a radiograph is affected by the focus-film distance. The greater the distance, within limits, between the focal spot and the film relatively the more definition is insured in the detail. If the immobilization of the part to be radiographed is under control, a longer period of exposure insures better detail, provided that the correct exposure time is not exceeded. All other factors remaining in conformity to the rendition of fine detail, the latter is further affected by the size of the focal spot. The finer the focal spot the sharper and better-defined are the recorded outlines of the cancellous bone tissue, and other delicate tissue structures. (See Focal Spot, Section 4, Chapter XVIII.)

The use of the Potter-Bucky diaphragm materially increases the definition of the softer structures of thick parts. If the field of exposure is confined as closely as possible to the portions whose radiograph is desired, by employing an appropriate size cone, a marked improvement is observed in the definition of the detail, as the effect of scattered radiation from the surrounding portions not desired in the area of examination will be precluded from the field of exposure.

4. Radiographic Contrast.—The difference of densities between the light and dark recordings of tissue structures and the degree of the distinguishable features of the surrounding medium constitute the contrast of the radiographic image. The chief factors affecting the degree of contrast are: The milliamperage, the time of exposure, the size of the focal spot, and the kilovoltage.

Other factors being equal, the higher the milliamperage the greater the radiographic contrast. Within a distance limit, and all other factors remaining constant, higher kilovoltages produce less contrast, but the visibility of the detail of both dense and soft tissues will be improved. If the magnitude of the applied kilovoltage that produces a satisfactory penetration is exceeded that which ensures a proper radiographic contrast the radiograph suffers from grayish "flat" appearance. On the other hand, too low a kilovoltage will cause an excessive contrast with loss in detail of soft structures. In order to obtain a proper contrast without particular regard to accentuation of the detail, the kilovoltage should be kept at a value just sufficient to produce the necessary penetration.

The question then arises, "Are lower kilovoltage technics more preferable in the production of a radiograph of high diagnostic quality?" Arthur W. Fuchs[1] boldly remarks that the conception that the lower kilovoltages increase the radiographic contrast and hence accentuate definition is fallacious. While some radiographers prefer the contrasty appearance of the radiograph, the sacrifice of definition that ensues deprives the radiograph from presenting the "information most needed for proper interpretation." In his opinion, "when a radiographic image is recorded with sharpness, contrast can be reduced appreciably without loss in the perception of detail," which appears quite feasible. Bouwers[2] further remarks that "by improving the sharpness of definition we do not improve the *physiological impression*[3] of sharpness in the same proportion," and hence he emphasizes the importance of a tube with higher specific rating capacity, which factor is only peculiar to rotating anode type of X-ray tubes.

When absolute immobilization is effected, increasing the time of exposure increases the contrast. With properly chosen radiographic energy factors, the tendency of the focal spot toward the production of higher radiographic contrast by producing finer detail with whites and blacks appreciably better-balanced is increased. The Potter-Bucky diaphragm in conjunction with an appropriate size cone proves an additional aid in

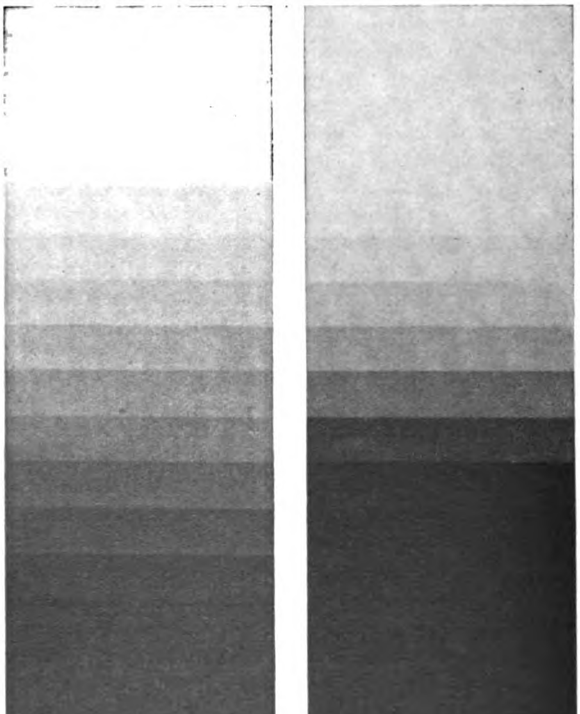
[1]Medical Division, Eastman Kodak Company, Rochester, N.Y.

[2]A. Bouwers, Technic of Instantaneous Radiograms, Philips Metalix X-Ray Research and Development, 1923-1937, Page 149.

[3]*Physiological impression* implies the radiographic recordings of moving visceral parts.

obtaining the desired effect of radiographic contrast, and longer development of the film will likewise increase this quality.

The fact that over-all increased contrast results in loss of visibility of the radiographic detail in the different density gradations of the image, when a high kilovoltage technic is employed the condition is altered with the realization of a low contrast together with small differentiation in the gradations of the different densities. Necessary detail, however, is obtained for proper diagnostic interpretation. If, however, the part to be radiographed transmits X-ray intensities comparatively to a small extent, a technic offering a high contrast will be more preferable. The effect is further illustrated in Fig. 155, which presents two radiographs of varying layers of sheets of Aluminum. The radiograph in (a) is taken with high kilovoltage technic, while that in (b) is taken with low kilo-kilovoltage. The photographs should assist in enabling one to determine whether a given part should be radiographed with high or low kilovoltage technic. As a rule, the softer tissue structures demand higher contrast, whereas bone structures in the thicker parts of the subject may be radiographed with higher kilovoltages, producing more moderate contrast.



(A) (B)
FIG. 155. ILLUSTRATING THE EFFECT OF KILOVOLTAGE IN PRODUCING DENSITY GRADATIONS.

5. Radiographic Distortion.—The radiographic image of an object is always slightly larger than the object itself. This is due to the divergence

of the X-ray radiation as it leaves the focal spot. When an image is magnified yet retains the true shape and outlines of the object radiographed, the effect is called a true distortion. If the enlarged image is distorted, twisted, or otherwise has lost the true outlines and shape of the object, the resulting quality is known as false distortion. (See: Object-Image Relation, Chapter XVIII.)

In radiography, distortion can be reduced to a minimum by increasing the target-film distance, and by aligning the object and the film in direct relation with the central X-ray beam. Close approximation of the object part to the film is of great importance, but when this can not be insured in a convenient manner, the tube distance is increased so as to offset the effect of enlargement otherwise would incur were the target-film distance smaller. An unnecessarily large focal spot causes haziness in the outlines of the part radiographed, and hence, an absorption of the sharp details together with a slight loss in the differentiation of density gradations and in the true shape of the object is manifested in the radiograph.

Distortion due to voluntary movement of the part radiographed may be eliminated by use of compression bands, sand bags, or by a towel stretched across the part and held taut by the operator or by securing the ends of the towel by means of sand bags. The involuntary movement in the visceral regions can be largely suppressed by asking the patient to hold his breath during the entire exposure. When necessary, high-speed high milliamperage technic must be resorted to in order to effect a complete reduction in the distortion due to involuntary visceral movement.

6. Latitude Of A Roentgenographic Film.—The latitude characteristic of a given radiographic film is the degree of permissible deviation of radiographic density from that of a properly-balanced normal radiographic quality. This quality may vary from 10 to 100 percent above or below the optimum and still an interpretable radiograph may be obtained. A film of high quality, for certain long technics, may compensate for any errors in exposure time. But, with exposures of 1/10 to 1/120 of a second

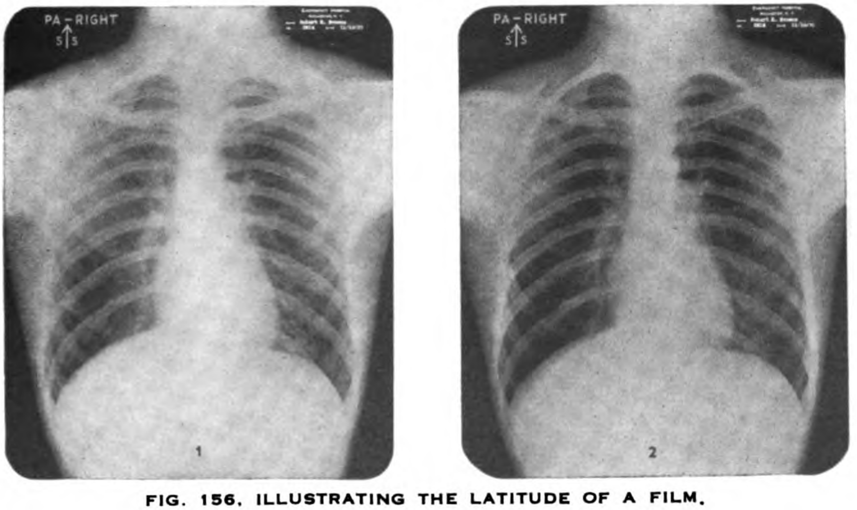


FIG. 156. ILLUSTRATING THE LATITUDE OF A FILM.

a slight error in estimating the exposure time may result in the blackening of the film of several hundred percent, whereby subversive characteristics of over-exposure effect is indicated, and the radiograph, in some cases, is not interpretable. Again, an X-ray film of good quality will compensate to a large extent to obviate this complication. In order to be able to judge whether or not the over-blackening effect in a radiograph is due to over-exposure or high-milliamperage, a standardized time-temperature procedure should be adopted and carefully observed—development of the film for five minutes at 65°F in a reasonably fresh solution.

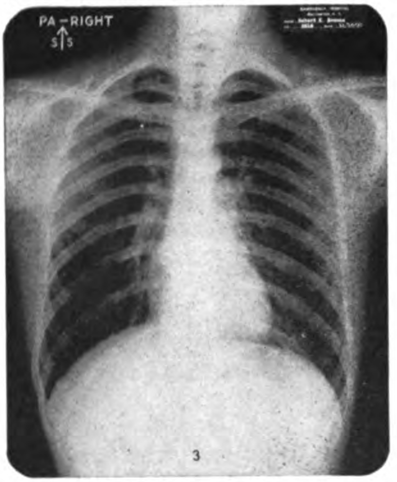


FIG. 156. ILLUSTRATING THE LATITUDE OF A FILM.

The effect of extreme film latitude is demonstrated by the reproductions shown in Fig. 156. All three of the radiographs of the same chest are made on Eastman Ultra-Speed X-Ray films and with standardized time-temperature development. It will be noted that in (1), which is made with half the normal exposure time, the interpretable features are competently comparable with that of (2) taken with normal exposure, whereas (3) is made with twice the normal exposure yet it possesses a moderate readable radiographic characteristic. The variation in exposure technics in (1) and in (3) in respect to (2) is respectively 50% and 200%. Again, we may state that such a bold comparison can only be featured for a film of highest inherent radiographic quality and of great exposure latitude.

It is further suggested by Fuchs[1] that with the combination of high-kilovoltage and High-Definition Screen (*exposure factor—1/8*) technic using Ultra-Speed X-ray film, with standard development, fewer errors are incurred in the estimation of the exposure time factors, because of the great exposure latitude dominant in these Ultra-Speed X-ray films. With higher kilovoltage technics (85 Kv.P. or above), a fully adequate penetration of the thickest part is realized, with the result that kilovoltage adjustments are seldom made, as compensation for the difference in the thickness to secure the desired density and contrast can be made by changing the milliampere-seconds factor.

In recent years, constant demand for successful radiography of moving viscera has given impetus to the development of a new ultra-rapid X-ray film[2] emanated from the Eastman Research Laboratories on May 10, 1940.

This important contribution possesses all the qualities characterizing the prevalent Eastman ultra-speed X-ray films—maximum contrast, ability to record most minute detail, exposure latitude, and uniformity—

[1]Radiography and Clinical Photography, pages 2-8, June, 1938.

[2]Commercially known as *Blue Brand Eastman Ultra-Speed Safety X-ray Film*, packed a distinctive blue top carton.

combined with increased speed, making it possible to *reduce present exposures 25%* and still obtain results of the same quality.

If it is desired to effect further reduction in exposure in a given technic, the time may be shortened to *one-half* by increasing the tension on the X-ray tube as indicated in the following table:

Present Kv.P.	40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85
New Kv.P.	44 - 50 - 55 - 60 - 65 - 71 - 76 - 82 - 87 - 93

(Halve the present exposure time.)

The greater speed of the film becomes of distinct advantage when high-definition intensifying screens are employed, in that, maximum contrast combined with a wealth of diagnostic detail is obtained with same exposure tensions as those formerly used for "fast" screens and ultra-speed film.

If desired and when absolute immobilization is effected, a *25% reduction in the milliamperage* instead of the exposure time can be made. The practice becomes significant when economy of the X-ray tube is a matter of concern. Gross[1] maintains that the operation of the X-ray tube with a *milliamperage 20% lower* than the manufacturer's rating chart lists tends to treble the life of the tube. Pertinent claims by Bouwers[2] attest to the consistency of the argument in this direction.

7. The Effect of Kilovoltage On Radiographic Definition.—In his article on higher kilovoltage technic, Fuchs[3] further expresses the opinion that "excellently balanced radiographs of greater diagnostic value" may be realized due to technical advancements in exposure procedures employing higher kilovoltage and High-Definition screen technic. The technic consists of the use of slower Eastman High-Definition screens (*factor—1/8*) together with Eastman Ultra-Speed X-ray films, a fine focus X-ray tube, a high ratio (8-1) Potter-Bucky diaphragm (when necessary), a low milliampere-seconds factor, and tensions of the order of 85 kilovolts or above exhibiting a complete control over the entire scale of density gradation of the radiograph. With such a procedure, extremely short exposures, within the load-carrying capacity of the X-ray tube, may be made with greater number of exposures per patient, since X-rays produced at these voltages are of short wave-lengths and hence the hazard of differentially absorption of the radiation by the body exposure area is decidedly minimized.

A glance at Figs. 157a, and 157b will readily convince one of the merits of the above technic on the ground that Fig. 157b, which uses the present technic herein described, reveals excellent detail with utmost sharpness in definition. Proper contrast combined with distinct visibility in both dense and soft tissues provide accurate interpretation of the radiograph. The reproduction in Fig. 157a is made by use of low kilovoltage technic and Ultra-Speed Screens, which lessen the sharpness of definition, as previously mentioned. Furthermore, the provision, by the low kilovoltage technic, of inadequate penetration renders the

[1]Gross, M.J.:—Factors Involved in the Rating and Testing of X-Ray Tubes. *X-Ray Tech.*, 5:15-20, July, 1933.

[2]Bouwers, A.:—Philips X-Ray Research and Development, 1937.

[3]Radiography and Clinical Photography, Page 2-8, June, 1938.

image less intrepretable and errors in diagnosis are likely to occur.

In the present technic, described above, by applying a higher kilovoltage to the X-ray tube no deleterious effects have been noted, it is

(A)

(B)

FIG. 157. RADIOGRAPH OF KNEE TAKEN WITH (A) PREVALENT LOW KILOVOLTAGE TECHNIC, AND (B) WITH HIGH-KILOVOLTAGE.

claimed. Increased secondary radiations that would otherwise affect the fine detail in the production of the image is precluded by the use of high-ratio grid (8-1) Potter-Bucky diaphragm.

8. The Quality of Definition In A Radiograph.—As stated in a previous section, definition is the chief determinant in a radiograph, and is dependent upon three component factors dictating the sharpness of the radiograph—namely, the geometrical unsharpness U_g due to the size of the focal spot, the motional unsharpness U_m arising from movement during exposure, and the screen unsharpness U_s resulting from the diffusion of the light of the fluorescent crystal. In a recent article*, Bouwers and Oosterkamp emphasize the fact that to minimize the phenomenon of unsharpness in a radiograph the three component unsharpness values must be approximately equal, thus:

$$U_g = U_m = U_s \tag{135}$$

and, the total unsharpness U will then be given as

$$U = U_g + U_m + U_s \tag{136}$$

In the expression (136), the value of U_g, when the target-film is fixed, may always be reduced to a minimum by selecting the finest focal spot tube that can withstand the particular load condition. Or, with a given focal spot, the target-film distance may be made, within radiation intensity limits, sufficiently large as to reduce distortion materially and hence the geometrical unsharpness U_g. But, the latter will curtail the lengthening of the exposure time with possible increase in U_m, which is proportional to the duration of exposure and the rate of movement of the parts under

*Unsharpness In a Radiograph, Philips Metalix X-Ray Research and Development. 1923-1937, pp. 143, 158-164.

examination. If the target-film distance is constant, using a tube focus of sufficiently large size will enable a reduction in exposure time. The use of the intensifying screens will further effect this reduction in exposure time but will correspondingly increase the unsharpness U_s due to the diffusion of the fluorescent light about the projected unit detail.

With High-Definition screens, which have fine-grained crystals, and, therefore, possess low intensifying factor, the sharpness will become more pronounced (U_s reduced), but the exposure has to be prolonged. This disadvantage may be obviated to a considerable extent by using a high-kilovoltage and low-milliamperage-second technic, thus reducing the tube load materially. Consequently, a moderately small-focus tube may be employed in the technic.

Bouwers[1] has in view of Chantraine's[2] experimental observations shown that the screen unsharpness U_s is to some extent proportional to the intensifying factor. By comparison of unsharpnesses between a series of exposures with different known geometrical unsharpnesses U_g and screens of different origins, a conclusive data giving the relative screen intensifying coefficient and screen unsharpness U_s have been obtained, as shown in Table X.

Table X:—Screen Unsharpnesses Relative To Intensifying Factors

Screens	Relative Intensifying Factor	Unsharpness in mms.
A	1.00	0.35
B	1.15	0.50
C	0.54	0.20
D	0.40	0.20
E	0.40	0.20

A study of Table X will show that the relative value of the intensifying coefficient of screen B is approximately 2.5 times that of screen E; and, in like manner, the corresponding proportionality in the relative unsharpness between the two remains respectively the same.

It is further explained by Bouwers that the load applied to the X-ray tube having a rotating anode is roughly proportional to the breadth of the focal spot, and that the time of exposure varies inversely as this width and also the intensifying factor of the screen.

Since the motional unsharpness U_m is in direct proportion to the duration of exposure, an equation expressing the existing relation between the two factors is given as

$$U_m = at \tag{137}$$

where a is a constant and has an average numerical value of 5 (the average

[1] A. Bouwers, Acta Radiologica 12, 1931, p. 175.

[2] Cf. H. Chantraine, Fortschr. Rontgenstr., 42, 1930, p. 108.

velocity in mms of moving visceral parts), and t is the time of exposure in seconds.

It will be noted that U_m is further inversely proportional to the screen intensifying factor and to the focus breadth of the tube. The relation may be represented as

$$U_m = \frac{a}{fK} \tag{138}$$

in which, f is the width of the focal spot, and K is the intensifying factor of the screen. From the last relation, it should be observed that U_m may be reduced to a minimum by adequate choice of intensifying screens and using the optimum size focal spot.

In conclusion, we may restate that the most favorable condition in the attainment of the minimum unsharpness in a radiograph is realized when all the three component qualities are equal to one another, as shown by equation (135). It can be easily shown that a reduction in any one component factor will result in an abnormal increase in the unsharpness value in one or both of the other factors so that a wide deviation from the optimum condition will be realized in the resulting radiograph. The relation $U_g = U_m = U_s$ can hardly be improved upon, as the component unsharpnesses are so interdependently distributed that a *"mutual balance"* in sharpness becomes at all times existent. Now, it could be maintained that with present X-ray apparatus and film material, the ideal condition of the improvement in radiographic sharpness is inclined toward the use of a fine-focus rotating anode, high-kilovoltage high-definition screen technic, high-ratio Potter-Bucky diaphragm, greatest possible target-film distance, and, above all, a fine-grained film of high quality.

9. Methods Of Marking The Radiograph.—In order to be able to properly identify a radiograph, it is essential that adequate identification markings, designating the name of the patient, the date and the serial number of the radiograph, and the firm title or the radiologist's name, be permanently recorded in the sensitized emulsion of the radiograph. In addition to these identification data, suitable lead letters to orient the right and the left side of the image should invariably be used on the exposure holder or the cassette during every exposure.

For identification of the various positions of the subject radiographed, lead markers designating the portion of the subject nearest the film are placed together with the legendary markers on one corner of the exposure holder. For instance, if the subject is interposed between the X-ray tube and the film in such a manner that his anterior aspect faces the tube and his posterior toward the film, the position is spoken of as *"Anterior-Posterior"*, and the markers to designate this will be *"A-P"*, the abbreviation of this position. If the anterior aspect is toward the film and his posterior or dorsal aspect faces the target of the tube, the position is known as *"Posterior-Anterior"*, and the film is marked by letters *"P-A."*

In some of the recent radiographic procedures, the adopted technic for designating the various parts of the subject is effected by indicating first

the part of the subject closest to the film, and next the part toward the X-ray tube.

Perforations of lettering or numerals in lead strips are commonly employed for radiographic identification. Writing on the cassette or on the exposure holder with a radio-opaque ink has been tried quite satisfactorily for permanently recording on the film the necessary data. But, presumably the most elegant method of marking radiographs is by means of an Identification Printer, shown in Fig. 158, recently announced by the Eastman Kodak Company. To use the apparatus, the identification data

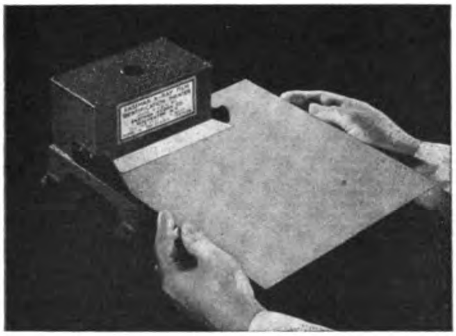


FIG. 158. THE EASTMAN IDENTIFICATION PRINTER.

are typed on the X-ray department requisition form, which is then placed on a corner of the unexposed film and inserted into the Printer which photochemically records the identification legend in the film emulsion. Before the film is radiographed, the corner bearing the latent image or the recordings is shielded by a lead strip from exposure to X-rays.

When the radiographic exposure is made, and the film is treated in the processing solutions, the identification data become a permanent part of the radiograph. In the writer's laboratory, a sheet of plastic material impregnated with a radio-opaque compound, and on which material identification data are stenciled, has been used with satisfactory results to record the legendary impression permanently on the film by means of the X-ray radiation during exposure.

These identification recordings, aside from affording a mere convenience in filing and consultation, offer a means of readily admissible evidence in medicolegal cases. Quoting from Dr. Donaldson's[1] article: "Proper and complete identification of all radiographs should be regarded by both physicians and dentists as malpractice prophylaxis. Any radiograph may find its way into the court room and if properly identified may be introduced as evidence. All radiologists and X-ray technicians should consider every radiograph subject to subpoena. Then identification suitable for all purposes will be the rule.

[1]S. W. Donaldson, Radiograph As Medicolegal Evidence, Radiography and Clinical Photography, Page 9, June—1938.

A radiograph may be the best evidence that due care and diligence have been exercised in the treatment of the patient, and in many cases failure to have radiographs made has been the basis for legal action.''

QUESTIONS ON CHAPTER XVII

1. (a) What factors enter into the constitution of a roentgenograph?
   (b) Discuss the procedure prerequisite to performing a radiographic examination.
   (c) State the elements entering into the obtaining of a sharp definition in a radiograph.
2. (a) How may an over-exposed radiograph be differentiated from those exposed to high voltage radiations?
   (b) Define, and give the factors constituting the radiographic density.
   (c) What characteristic features may be possessed by a radiograph for making itself diagnostically useful?
3. (a) What constitutes detail? How may the maximum detail be secured in a radiographic image?
   (b) Illustrate the effect due to the size of the fluorescent crystals in relation to the definition of the radiographic image.
   (c) For obtaining the maximum definition, is a cardboard exposure holder superior to intensifying screens? Why?
4. (a) How does the focus-film distance affect the radiographic detail?
   (b) Discuss the place of the focus size, Potter-Bucky diaphragm, and cones in the accentuating of the definition in a radiograph.
   (c) What is a radiographic contrast? On what exposure factors is it dependent?
5. (a) Of what diagnostic value is a high-kilovoltage technic in preference to low-kilovoltage methods?
   (b) To what optical properties of X-radiation is the distortion in a radiograph due?
   (c) Explain how distortion may be minimized in a radiographic image.
6. (a) Define latitude of a roentgenographic film. On what inherent characteristics of the film is latitude dependent?
   (b) Compare the diagnostic value of the prevalent low-kilovoltage technic with that using high-kilovoltage and high-definition screens.
   (c) Upon what component factors is the sharpness of a radiograph dependent?
7. (a) Explain briefly the relations of U_g, U_m, and U_s to the quality of definition in a radiograph.
   (b) To what extent is the relative screen intensifying coefficient related to screen unsharpness? How does the crystal structure of the fluorescent material affect the screen unsharpness?
   (c) How may the most favorable condition in the attainment of the minimum unsharpness in a radiograph be realized?
8. (a) What relation is borne by the breadth of the focal spot of a rotating-anode X-ray tube to the sharpness of the radiograph?
   (b) Give the methods of recording identification markings in the emulsion of a radiograph. Of what importance are identification markings in medicolegal cases?

CHAPTER XVIII

ROENTGENOGRAPHIC ALIGNMENT

1. Optical Principles As Applied To X-Rays.—As mentioned in the preceding chapter, a radiograph is a shadow recording of an object intercepting a beam of X-radiation. Since this radiation behaves, in many respects, in the same manner as visible light, the shape and the size of the resulting radiographic image is dependent upon the relative position of the object in respect to the focal spot and the film. Consequently, we must have recourse to the study of optical principles treating, in a general way, the relative subject of light propagation.

Taking light as an analogy for X-rays, many facts pertinent to the behavior of X-rays can be easily explained. For instance, practically every one has had the common experience of standing close to a source of light and seeing the heavy large shadow of his figure cast upon his surroundings. As the person recedes from the light source and moves close to the shadow-receiving surface, his shadow becomes smaller and smaller; and, when he is furthest from the light source and closest to the surface of shadow formation, his shadow becomes practically the same size of his figure, as then the deviation of the radiation rays occur almost in parallel lines. In such a case, it becomes evident that the farther the person or object from the source of light the more nearly-parallel become the rays of the radiation. Hence, the object casts a shadow equivalent to its size or outlines, on a surface perpendicular to the radiation beam.

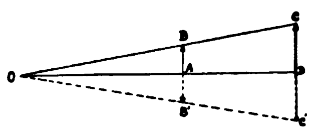


FIG. 159. ILLUSTRATING OBJECT-SHADOW RELATIONS.

Since light propagates in straight lines, the size of the shadow cast by an object is proportional to that of the object in the same ratio as the distance of the shadow from the source of radiation is to that of the object from this source. For instance, in Fig. 159, O is the source of radiation, and CD is the shadow cast by an opaque object BA. Furthermore, the right triangles OBA and OCD are similar, since the corresponding angles are equal. In similar triangles corresponding sides are proportional. Hence, we may equate

$$\frac{OA}{OD}=\frac{BA}{CD}$$

in which, OA and OD are respectively the distances of the object and the shadow from the source of radiation O, and BA and CD are respectively the sizes of the object and its shadow image.

If we designate the object-source distance by D_1 and image-source distance by D_2, then we may write the following expression:

$$\frac{\text{Size of Object}}{\text{Size of Image}}=\frac{D_1}{D_2} \tag{139}$$

With similar reasoning we may show that

$$OA : OD :: B'A : C'D$$

and, if the size of the object were BB' and its midpoint A were perpendicular to the radiation, as shown in Fig. 159, we arrive at an expression

$$\frac{BA+AB'}{CD+DC'}=\frac{BB'}{CC'}=\frac{D_1}{D_2}$$

in which, CC' is the size of the shadow. Expressing this relation in terms of the sizes of the object and the image, we have

$$\frac{\text{Size of Object}}{\text{Size of Image}}=\frac{D_1}{D_2}$$

From these derivations it is obvious then that the size of the images is always proportional to that of the object as the corresponding distances from the source of radiation are to each other.

2. Object-Image Relations.—Treating a beam of X-rays as light, and allowing the ray to become perpendicularly incident upon a radio-opaque object, the latter will cast a shadow in accordance to its relative position between the anode and the shadow-receiving surface. In Fig. 160, assuming that a beam of X-rays projecting from a point A on the focal spot falls upon a lead sheet P, 4 square inches in area and placed 20 inches from the source. If now a fluoroscopic screen S is placed 40 inches from the X-ray source A, a shadow of the lead object will be formed on the screen. Since the object is midway between the source of radiation and the screen it is by no means in close relation with the surface of the latter. Hence, the image thus formed will be comparatively larger. More precisely, the shadow image of the lead will have an area four times as large, as illustrated in Fig. 160.

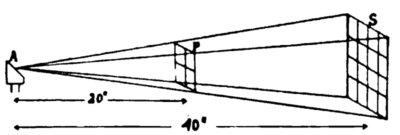


FIG. 160. OBJECT MIDWAY BETWEEN THE FOCAL-SCREEN DISTANCE.

Sustaining the focus-screen distance constant (40 inches), suppose the object P is moved to a position 5 inches from the surface of the fluoroscopic screen, as in Fig. 161. The shadow cast by P will be much smaller and sharper in its outlines than that shown in Fig. 160. It is thus obvious, that the farther the object from the source of X-rays, within limits of practicability, and the nearer to the shadow-recording surface, the resulting image or shadow will be less enlarged. Moreover, for optimum results the plane of the object should be as parallel as practicable to the

surface of the recording material (fluoroscopic screen, or film), and the principal ray should be incident normally to the center of the exposure field. Such conditions should be met as always as is possible in the position-

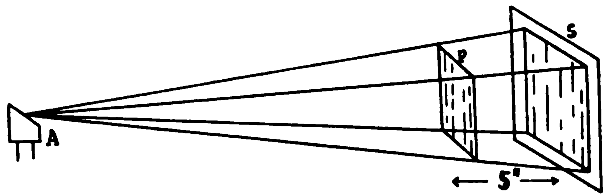


FIG. 161. OBJECT NEARER TO SCREEN THAT TO ANODE.

ing of a part under examination, if a proper radiograph with least amount of distortion and having a sharp definition is expected.

The relation of the size of the object to that of its shadow, and the relative target-object and target-film distances are further explained in the following rule form:

The Rule:—*The size of the shadow is proportional to the size of the object as the distance of the shadow-recording surface from the source of X-rays is proportional to the distance of the object from this source.*

Representing this relation in an equation form, we obtain

$$\frac{S_1}{S_2} = \frac{D_1}{D_2} \tag{140}$$

where S_1 stands for the size of the object and S_2 for that of the shadow, and D_1 and D_2 are respectively the focus-object distance and focus-screen distance.

Examples:—(1) An object, 6 inches wide, is placed 18 inches from the target of an X-ray tube. If the target-film distance is 30 inches, what will be the width of the shadow image of the object?

According to equation (140), we have

$$\frac{S_1}{S_2} = \frac{D_1}{D_2} \qquad \text{where,} \quad \begin{aligned} S_1 &= 6 \text{ inches} \\ D_1 &= 18 \text{ inches} \\ D_2 &= 30 \text{ inches} \end{aligned}$$

and,

$$S_2 = \frac{S_1 \times D_2}{D_1} = \frac{6 \times 30}{18}$$

$$= 10 \text{ inches.} \qquad \textit{Ans.}$$

(2) A shoulder is placed on an X-ray table top which is 2 inches from the radiographic film. If the focus-film distance is 30 inches, and the part of the shoulder to be radiographed is 9 inches wide and 5 inches thick,

(Note:—When the thickness of the patient's part is given, the target-object distance is measured from the focal spot to an imaginary line at half the thickness of the part to be radiographed.)

what amount of distortion (magnification) will be produced in the radiographic image?

Since the thickness of the part is 5 inches, and the part lies 2 inches above the film, then the focal-object distance D_1 will be 30 - 2 - 2.5 = 25.5 inches. Hence, the size of the image will be

$$S_2 = \frac{S_1 \times D_2}{D_1} \qquad \text{where,} \quad \begin{aligned} S_1 &= 9 \text{ inches.} \\ D_1 &= 25.5 \text{ inches.} \\ D_2 &= 30 \text{ inches.} \end{aligned}$$

$$= \frac{9 \times 30}{25.5} = 10.58 \text{ inches.}$$

and, the magnification of the image is given as

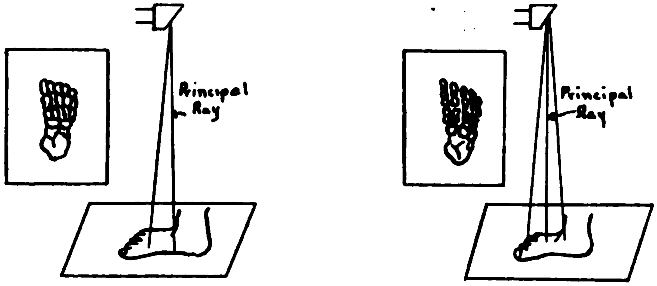
$$10.58 - 9 = 1.58 \text{ inches.} \qquad \textit{Ans.}$$

It should be kept well in mind that distortion due to magnification is prevalent practically in every radiograph. The greatest amount of magnification will occur when the part radiographed is farthest from the film. Accordingly, to reduce the condition to a minimum, the focal-film distance must be increased to a practicably large distance, the object-film distance should be made as small as possible, and the smallest focal spot consistent with the tube load required by the given radiographic technic must be used.

3. Target-Object-Film Alignment.—In the attainment of a sharp, true shadow of a part radiographed, another important factor of further consideration is the alignment of the area of interest in respect with the focal spot and the recording surface. The principal ray, which projects in a normal aspect to the axial plane of the target and is of least divergent character, should be directed perpendicularly to the center of the field of examination and to the film. If close approximation of the part to the film can not be effected due to the interposition of a Potter-Bucky diaphragm, or, in view of the presence of a thick plaster cast about the area to be radiographed, the target-film distance may be increased so as to offset the tendency for the structures remotest from the recording surface from becoming superfluously enlarged.

When the above conditions are complied with, the resulting radiograph will be free from false distortion, and the true shapes and outlines of the structures under examination will be conserved. To further illustrate this, Fig. 162a represents the incorrect positioning of a right foot in respect with the principal ray, which is directed out of the center of the area to be radiographed. The resulting radiographic representation is shown on the left side of the figure. It will be noted that the metatarsals and the phalanges are distorted and appear as if overlapping one another. Naturally, any impairment or pathological condition of the bones can not be detected from the image made with such positioning technic. On the other hand, Fig. 162b, in which the principal ray is directed to the area of interest, shows the correct angulation of each bone in respect to the primary radiation. Thus, the peripheral regions of demarkations, interosseous spaces, and the normal relations of bone articulations are plainly visible, enabling the detection of an abnormal condition, if any, in the area of

examination. In such a positioning, if the X-ray tube is properly distanced, false distortion practically reduces to insignificance.



(A) INCORECT POSITIONING. (B) CORRECT POSITIONING.
FIG. 162. POSITIONING OF A PART IN RESPECT TO THE PRINCIPAL RAY.

It becomes obvious, then, that if the attainment of a radiograph with the most interpretable features is sought, the alignment of the part in correct relation to the central X-ray radiation is of primary importance. To accomplish this, the principal ray should always fall on the center of the area of radiographic interest.

4. The Relation Of The Focal Area To The Definition Of The Image.— The formation of shadows by X-rays closely follows the optical principles relative to visible light. That is, when light propagates from a point source, any object intercepting the radiation within a reasonable distance from the source casts, on a nearby screen, a shadow having more or less sharp and well-defined outlines. This is due to the fact that since light rays travel in straight lines a given beam of light projecting from a point source will fall on a given portion of an object at only one incident angle. Hence, each point of the image will be constituted by the shadow of one and only one corresponding point of the object. A great number of such shadow points will then form the entire shadow image of the object.

On the other hand, if the beam of light is projected not from a point source but from a small area, each point in this area will produce a com-

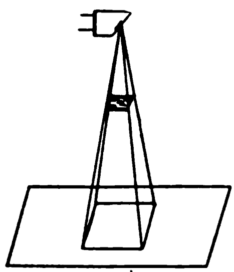


FIG. 163. SHARP OUTLINES DUE TO A FINE FOCAL SPOT.

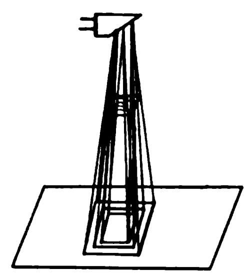


FIG. 164. HAZY LINES DUE TO A LARGE FOCAL SPOT.

plete shadow of the object. Thus, the resulting shadow image of the object will consist of a series of superimposed shadows of the object, and there-

fore, the definition of the outlines of the image will be impaired to a considerable extent.

In the formation of X-ray shadows, same principles as of light apply. The smaller the focal spot area consistent with the applied power required by the given technic, the more uniformly concentrated are the diverging rays, with the result that a sharper and better-defined radiographic image will be obtained. The relation between the definition of the radiograph and the size of the X-ray tube focus is better understood by a reference to Fig. 163, which illustrates the formation of a sharp image on the recording surface by an object intercepting the X-ray radiation proceeding from a fine-focus X-ray tube target.

The energy applied to a rotating anode X-ray tube having a fine focus may be increased as much as ten times that employed on a stationary anode of equal focal spot area. Since at maximum distances definition of the image is improved, by employing at the same time a fine-focus rotating anode tube, the load to the X-ray tube may be increased, with the consequent shortening of the exposure time and of reduction in the unsharpness due to movement. Thus, conditions for producing the optimum sharpness in the definition of the radiographic quality are realized.

In the case of a broad focus tube, unless sharpness of definition is of primary importance, a large target-to-film distance will considerably aid in improving the radiographic quality. Since a broad focal spot affords the impression of a larger load on the X-ray tube, a substantial decrease in motional unsharpness in view of the shorter exposure time is secured. The use of such a tube is of advantage in the radiography of the chest, gastro-intestinal series, and the entire spine at seventy-two inches distance.

For distances for ordinary radiographic technics, such as 25 to 36 inches the deleterious effect of a broad focus tube on the definition of the radiograph may be illustrated by referring to Fig. 164. It becomes evident from this figure that a multiplicity of images of the same part of exposure is formed on the film owing to the radiation of the part by X-rays issuing from various points on the focal spot. The resulting radiograph is devoid of the delineation of fine detail characteristic of a radiograph made by a fine focus X-ray tube.

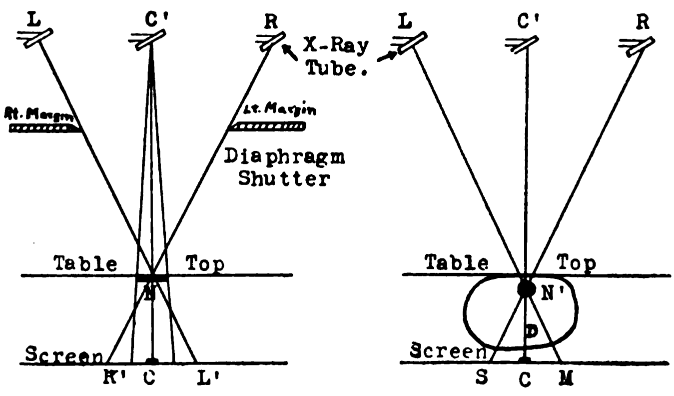
In consequence of the above conditions, it will be obvious then that in order to secure the optimum radiographic quality in an image, the X-rays should proceed from as fine a focal spot as possibly consistent with the loading capacity of the tube. A practicably large target-object distance together with proper alignment of the object and the film in relation to the source of radiation becomes of special significance. For the radiography of the extremities, for example, a fine focus tube is considered advantageous at shorter distances and hence at lower loading capacities, whereas for thicker parts, a broad-focus tube at increased distances assures more satisfactory photographic effect in the resulting radiograph.

5. Localization of Foreign Bodies.—While in time of peace fewer occasions will lend themselves to the practice of localization of foreign bodies, during war attention is chiefly directed toward the applications of this phase of radiography. Of the various methods of localization the "*fixed angle*" method appears to be the most generally adopted in view of the

accuracy with which the location of the foreign body is determined.

The purpose of the *"fixed angle"* method is to depict two similar triangles and then to make a comparison between the respective altitudes by equating the ratio of the latter with that of the bases of the triangles. Since the two bases and the altitude of one of the triangles can be directly measured in the procedure, the altitude (depth of the foreign body from the screen) of the second triangle may be readily computed.

In practice, the application of the method accrues the alignment of the focal spot of the X-ray tube in normal respect to the center of the fluoroscopic screen, and the horizontal movement of the X-ray tube in reverse directions and equidistant from the center point of the screen. This is accomplished by first centering the fluoroscopic screen in perpendicular respect to the X-ray tube target. The fluoroscope may be centered (for horizontal fluoroscopy) by standing a medium size nail or screw (about 2 inches long) on its head upon the X-ray table top, and by simultaneously shifting the position of the X-ray tube and the screen until a round shadow consistent with the shape of the nail head is depicted on the center of the fluoroscopic screen, shown as C in Fig. 165a. Mark, on the screen, the center of the circular shadow with a wax pencil, as at C. Open the diaphragm aperture to its full extent, and replace the nail by a lead disc of same diameter as the nail head. Next, shift the X-ray tube to the right, as at R, to such a position that the shadow of the margin of the diaphragm across from the X-ray tube is superimposed exactly on that of the left margin of the lead disc, as at R' in Fig. 165a. Make a mark with the wax pencil. Move the tube to the left, as at L, until the image of the left margin of the diaphragm is just superimposed on that of the right margin of the lead disc, as at L'. Mark again, this point.



(A) (B)
FIG. 165. ILLUSTRATING THE METHOD OF LOCALIZATION OF A FOREIGN BODY.

Since the above procedure is carried out with X-ray room darkened, it will be found more expedient to turn on the lights now for taking the actual measurement between the markings $R'L'$, the target-to-table-top distance $C'N$, and the table-top to screen distance NC.

In Fig. 165a, RL is the distance of the X-ray tube shift in inches and represents the base of the triangle RNL. Similarly, the base $R'L'$ of the

triangle $R'NL'$ represents the distance that the image has moved on the fluoroscopic screen with the displacement of the X-ray tube from R to L. $C'N$ and CN are respectively the altitudes of the triangles RNL, and $R'NL'$ and may be accurately measured by means of a ruler.

Keeping the target to table-top distance and the screen to table-top distance constant, the part of the patient lodging the foreign body is interposed between the table-top and the screen. After the X-ray tube is so centered that the image of the foreign body falls on the mark C, (Fig. 165b) the tube is displaced from C' to R, a shift of same distance as for test object. A mark, as at S, is made with a pencil on the fluoroscopic screen. Then the tube is moved an equal distance from the center to position L and again the screen is marked as at M. SM represents the distance through which the image of the foreign body has moved with a shift of the tube from R to L.

Now, the triangles $R'NL'$ and $SN'M$ are similar, and from known geometrical considerations of the sides of similar triangles, we have the relation

$$\frac{CN'}{CN} = \frac{SM}{R'L'} \tag{141}$$

Since CN, SM, and $R'L'$ can be measured, it is then an easy matter to compute the value for CN', the depth of the foreign body from the fluoroscopic screen, by equating

$$CN' = \frac{SM \times CN}{R'L'} \tag{142}$$

Assuming that the distance between the table-top and the screen, CN, is 7 inches, the distance $R'L'$ 5 inches, and SM is 3.5 inches, and further assuming that the fluoroscopic screen stands one inch from the surface of the subject, then, according to equation (142), the depth of DN' of the foreign body from the surface of the subject will be determined by the relation

$$DN + 1 = \frac{SM \times CN}{R'L'}$$

or,

$$DN + 1 = \frac{3.5 \times 7}{5} = \frac{24.5}{5}$$

and

$$DN = \frac{24.5 - 5}{5} = \frac{19.5}{5} = 3.9 \text{ inches. } \textit{Ans.}$$

In another method, the localization of the foreign body is accomplished by measuring the target to fluoroscopic (or film) distance, the distance through which the X-ray tube is moved, and the distance of the corre-

sponding displacement of the image of the foreign body. In Fig. 166, *S* represents the source of X-rays, *B* the foreign body located in subject *P*, and *M* and *M′* its images produced with the X-ray tube respectively at

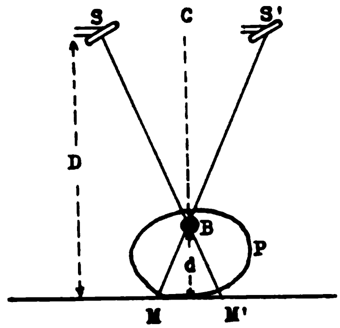


FIG. 166. LOCALIZATION OF A FOREIGN BODY.

positions *S* and *S′*. In the figure, the triangles *MBM′* and *SBS′* are similar and knowing the value of *D* (by measuring) the depth *d* of the foreign body *B* is readily computed by the following expression:

$$d = \frac{MM' \times D}{MM' + SS'} \tag{143}$$

Example:—A patient's part lodging the foreign body stands against a fluoroscopic screen (or lies on a loaded cassette) which is 20 inches from the X-ray tube target. When the tube is shifted 4 inches to either side from the central position, the image moves through a distance of 2 inches. What must be the depth of the foreign body from the fluoroscope (or, from the film, if subject is radiographed)?

According to equation (143), we have

$$d = \frac{MM' \times D}{MM' + SS'} \qquad \text{where,} \quad \begin{aligned} MM' &= 2 \text{ inches.} \\ D &= 20 \text{ inches.} \\ SS' &= 8 \text{ inches.} \end{aligned}$$

$$= \frac{2 \times 20}{2 + 8} = \frac{40}{10} = 4 \text{ inches.} \quad \textit{Ans.}$$

It will be obvious from Fig. 166 that in localization with a fluoroscope the points *M* and *M′* may be directly marked on the skin with a fountain pen. The midpoint between these two marks will locate the position of the foreign body on the normal to the skin. For finding the exact location of the foreign body, however, it is essential that two localizations at right angles to each other be made, the second localization marking the position in which the removal of the foreign body is to be undertaken.

In the case of a foreign body in the chest, abdomen, or in the thigh, where two views at right angles to each other can not be obtained, a simpler method for locating the exact position of the foreign body is to hold a lead strip (lead sheet measuring 3 mm by 5 mm, and attached to the end

of a ruler) at various points along the skin laterally to the body. When this is held opposite to the foreign body and in the same plane as the central ray, and simultaneously the X-ray tube is shifted back and forth so that the images of the foreign body and the lead strip are viewed moving parallel to each other through equal distances on the screen, localization is then effected. For instance, in Fig. 167 is shown the part of the patient P, with a foreign body O, placed against the table-top T.T. The test object

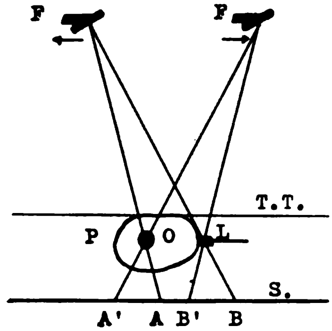


FIG. 167. PARALLAX METHOD OF LOCALIZATION.

L is so positioned in respect to the foreign body that when the X-ray tube is displaced sideways from F, for instance, to F', the image of L covers a distance BB' equal to that AA' covered by the shadow of the foreign body O. The point at the skin where the test object exhibits this effect is marked with indelible ink. This indicates the level at which the foreign body is located.

When the foreign object is in a limb, the latter is placed on the X-ray table in some convenient position. The X-ray tube is centered to the foreign object, and while viewing with the fluoroscope a blunt probe is inserted between the screen and the limb and moved back and forth until its shadow coincides with that of the foreign body. A mark is made on the skin at this point. A similar procedure is carried out at right angles to the previous position, and the skin is again marked at this point where the image of the pointer is exactly superimposed on that of the foreign body.

Having thus determined the position of the foreign object, the patient is placed in an operative position, and an incision is made in the skin. A pair of blunt-nosed forceps are introduced into the incision as far as to the foreign body, and while viewing with the fluoroscope, the jaws of the instrument are opened to extend about the foreign body. The forceps are pushed slightly farther and the object is grasped, as nearly as possible, along its long axis, and consistently pulled while pressing at the same time with the forceps against one side of the dissected tissue. Whenever the object can not be dislodged by procedures as herein outlined, recourse must be had to dissecting it out.

6. Thickness Determination Of A Metal Plate.—A slightly modified method of that for locating foreign objects in the body is the one for measuring the thickness of metals. In industrial radiography, frequently it becomes desirable to determine the thickness of the metal plate, for in-

stance, of a boiler, water mains pipe, or of the corroded area of a ship-hull. The radiograph is made without dismounting or physically harming the material. Fig. 168 illustrates the scheme for making accurate measurements of the thickness of a given metal.

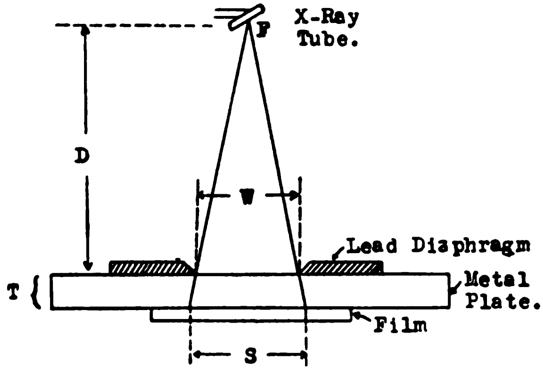


FIG. 168. DETERMINATION OF THE THICKNESS OF A METAL PLATE.

This method embodies the positioning of the X-ray tube at a known distance D from the metal plate to be inspected. A lead diaphragm is placed in close contact with one surface of the plate, which is then radiographed on a film placed next to its opposite surface.

The aperture of the lead diaphragm is usually adjusted to a convenient width W, and accurately measured. The shadow S of the metal plate exposed to the X-radiation can be measured on the finished radiograph. Knowing the target-plate distance D, the width of the diaphragm aperture W, and the corresponding width of the object image S, the thickness T of the metal can be accurately determined by equating the following geometric relation: In Fig. 168, the triangles FAB and FCD are similar, and hence we have the relation

$$\frac{W}{S} = \frac{D}{D + T} \tag{144}$$

and, equating the expression for T, we obtain

$$T = \frac{D \times S}{W} - D \tag{145}$$

in which, the thickness T is given in centimeters or inches, according to whether the other quantities are measured respectively in centimeters or inches.

If the film is placed at a distance R from the plate, the expression (145) becomes

$$\frac{W}{S} = \frac{D}{D + T + R}$$

or,

$$T = \frac{D \times S}{W} - D - R \tag{146}$$

The application of this method finds wide use in metal industry where accurate knowledge of the size or thickness of parts that are exposed to constant wear and tear is desirable in order that replacements, where necessary, can be afforded.

7. **Stereoradiographic Relations.**—The localization of foreign bodies may also be accomplished, in case two views at right angles can not be realized, by taking two stereoradiographs, which will present distinct advantages particularly if the regions under examination contain a considerable quantity of radio-opaque material. The cranium, the chest, shoulders, pelvis, the pelvic joints, or the vertebral column, which are sufficiently dense to cast shadows on the radiographic film, yield the desired information of the relative position of the foreign body to the neighboring tissue structures. Stereoradiographs afford the visualization of the field under examination in third-dimensional perspective, while a plane radiograph only reveals the breadth and the height of the image.

Stereoradiographs are made by radiographing the part under interest from two slightly different standpoints. This is performed by displacing the X-ray tube to one side a measured distance, for instance 1.5 to 4 inches, from the central position, and then making an exposure in the usual way. The exposed film is removed, and a second film is placed in exactly the same position. The X-ray tube is then moved to the opposite direction an equal distance (as the first shift) from the normal position, and a second exposure is made. The total displacement of the tube will then be 3 to 8 inches, in accordance to the nature of the part to be radiographed and the distance of the target from the exposure field. In making these radiograms it is essential, however, that the same exposure technic be used in both exposures in order to obtain an equal degree of density in the resulting image.

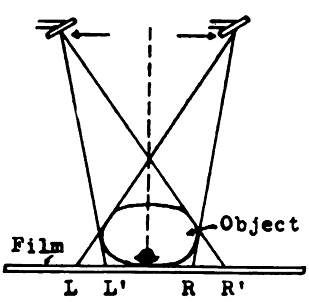


FIG. 169. TAKING A STEREOSCOPIC RADIOGRAPH.

The stereoradiographic procedure is illustrated in Fig. 169. Two views of the object are made on two separate films by shifting the X-ray tube

an equal distance to either side from the normal position, marked by dotted lines. The arrows represent the direction of target displacement. This displacement may be directed in a plane either vertically up and down or horizontally to the left and right of the patient. The plane of the direction of displacement depends on the predominating lines in the area under examination; therefore, the roentgenologist should use his discretion on this, since certain bone structures reveal a better view with longitudinal (*vertical*) shift while others with lateral (*horizontal*) shifts. At any event, however, the shifting of the X-ray tube should be directed at right angles to the predominating lines.

It is preferred that exposures of stereographs be not made at anode-film distances shorter than 25 inches, while longer distances, as high as 96 inches, are quite permissible, provided that a corresponding increase in tube shift is also procured.

The eye-image distance at the stereoscope is determined on the basis of 25 inches of anode-film distance and a tube shift of 2.5 inches, which corresponds to the interpupillary distance (distance between the eyes). At this ratio, a 25 inch anode-film distance necessitates the shifting of the X-ray tube through 2.5 inches. Hence, for larger target-to-film distances, the tube shift should be correspondingly increased; that is, the shift should be approximately ten-percent of target-film distance. For instance, for a target-film distance of 30 inches, the corresponding tube shift will be 3 inches; for 36 inches, it will be 3.6, etc., so that the ratio of 25 to 2.5 is at all times conserved.

A much accurate relation between the anode-film distance and tube shift, and the corresponding viewing distance on the stereoscope is shown in Table XI, prepared by Eastman Kodak Company.

Table XI:—The Relation of Anode-Film, Eye-Image and Tube Shift Distances.

Anode-Film Distance	Stereoscopic Tube Shift for Eye-Film Distances 25″	28″	30″
25″	2 9/16″	2 1/4″	2 1/16″
30″	3 3/16″	2 3/4″	2 9/16″
36″	3 7/8″	3 7/16″	3 1/8″
42″	4 5/8″	4 1/16″	3 3/4″
48″	5 3/8″	4 11/16″	4 5/16″
60″	6 13/16″	6″	5 1/2″
72″	8 5/16″	7 1/4″	6 11/16″
84″	9 3/4″	8 1/2″	7 7/8″
96″	11 3/16″	9 13/16″	9 1/16″

In recent years the importance of stereoradiography is becoming so prominent that the procedure is being adopted by many radiologists as routine practice in the diagnosis of overgrowths, tumors, fractures, calcification between articulations, or atrophied regions, in the lungs, skull,

thoracic walls, spinal column, abdominal cavity, and other visceral structures. The procedure becomes especially valuable in cases where the complication lies in the superimposed or overlapping structures, since not only the true shape and the relative size of the structures of specific interest are viewed more diagnostically by being thrown into a marked relief but also their relative depths in relation to the surrounding tissues or other structures may thus be determined.

In tuberculosis of the lungs, an atrophied portion of the lung tissue, the calcification of the broncheal cavities, or other complications arising from the collapse of a portion or the entire lobe of the lung, are readily detected and diagnosed when stereoradiographs of the lungs are available. Fracture of the skull, dislocation of a cerebral lobe due to an injury, calcification of the interarticular cartilages in arthritis, and fractures of any nature of the bony thoracic frame are examined more diagnostically when these parts are stereoradiographed. Stereoradiographing of an embedded root of a tooth, or of an impacted wisdom tooth sometimes proves to be an indispensable procedure prior to the extraction of the tooth from the jaw. In the procedure for measurement of cephalic diameters of a foetus in a pregnant woman, and in the localization of a foreign body in the throat, stomach, lungs, broncheal tubes, abdomen, or in any other part of the body, stereoradiographic views present themselves as further aid to the radiologist or to the surgeon in determining the specific procedure to be undertaken.

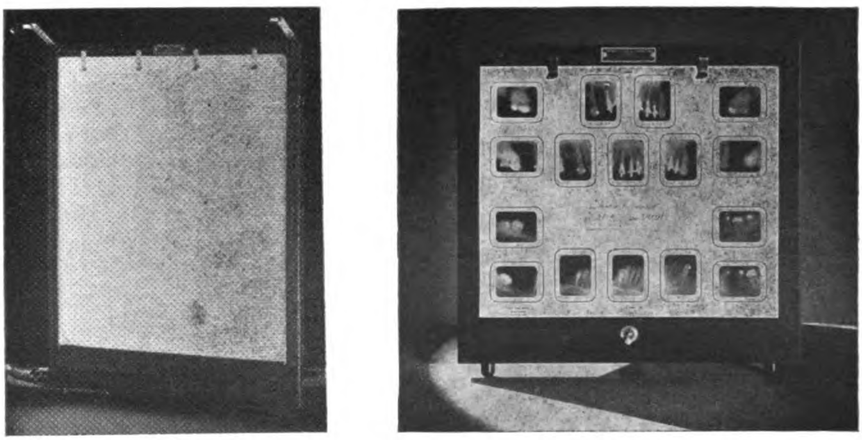
At the present day, attention is being directed toward obtaining internal diagnosis of the lungs and stomach through chiefly stereoradiographs. For this reason many manufacturers of X-ray equipment are working in an endeavor to design and market a practical and inexpensive apparatus possessing the characteristics and performance of any conventional bulky and costly stereoscopic apparatus. Among radiologists, a desire for simpler methods for radiography, and hence, the necessity of standardized technic is rapidly gaining ground. A technic evolved and successfully used by one radiographer may be too complicated to be universally adopted and used by another who may not be able to apply it with the same outstanding success. Therefore, an important stride towards standardization of stereoradiographic methods is the introduction of Philips Metalix stereoscopic X-ray apparatus.

It is claimed by the manufacturer that wtih this apparatus stereoradiographing has become an extremely simple matter, as the apparatus can be easily operated without the necessity of previous experience. The incorporation of an X-ray tube of focus 1.2 mm together with 2 mm Aluminum filter enables the attainment of surprising definition of bones in the extremities and the use of a much shorter target-film distance. The apparatus takes radiographs measuring 18 by 24 centimeters at a focus-film distance of 50 centimeters. Two such radiographs are taken on a 30 x 40 centimeters film using a tube displacement of 5 centimeters. Since the distance between the centers of the two images is short, about 19 centimeters, the question of distortion becomes altogether a negligible matter.

Furthermore, owing to the permanent connection of the tube and the cassette to the apparatus, no focusing is necessary. The part under examination is merely placed on the aperture (18 x 24 cms. in dimensions) of

the cassette and radiographed. The radiographs, being exactly parallel, may be viewed with a stereobinocular instrument, or they may be cut into two separate radiographs and viewed with any ordinary stereoscopic apparatus.

8. Viewing Radiographs; and, Stereoscopic Examination.—After the exposed film undergoes proper treatment in the processing solutions it may be mounted, preferably after it is dry, on an illuminator for examination. In order to realize full advantage from an illuminator, the quality of its radiation should approximate north daylight, and the illumination should be evenly diffused so as to bring out even the faintest detail recorded in the radiograph. The desirability of selection of the proper illumination to effect optimum interpretative value becomes essential in making provisions for a diagnostic study of the radiograph. An image having the highest requisite radiographic quality may lose its diagnostic value if viewed by means of a poorly designed illuminator furnishing inadequate illumination. On the other hand, by using a blue-tinted flashed opal glass plate illuminated by a proper intensity electric bulb, the diagnostically inferior characteristics of the radiograph may be enhanced materially.



(A) (B)
FIG. 170. X-RAY ILLUMINATORS.

A most effective equipment of the type described as preferable is the one obtainable from any leading photographic supply house, such as Eastman Kodak Company, and others. Figs. 170a and 170b respectively present a 14 x 17 in. vertical and 8 x 10 in. horizontal Eastman illuminators. Either type is provided with a convenient switch on the front for varying the light according to radiographic density. Three variations of light intensity —low for light, intermediate for average, and high for dense radiographs —obtainable from the illuminators makes the accentuation of the most minute detail possible.

The provision of spring-clip fingers to afford the securing of the dry radiograph against the glass plate, and bracket-arms for holding wet radiographs in their hangers, presents convenience to the radiologist who may

desire to study the radiograph after or before it is dry. A further and distinct advantage of the illuminator is accrued in the fact that two or more of the apparatus may fit closely together to form a bank so that more than one radiograph, presumably of the same part taken from different viewpoints, may be viewed at the same time.

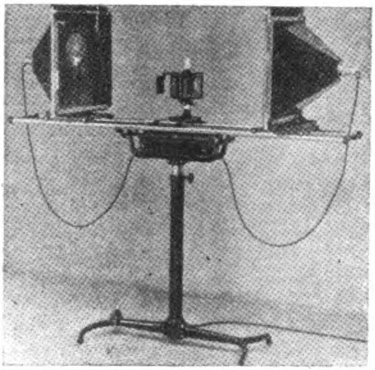


FIG. 171. WHEATSTONE STEREOSCOPE. (VICTOR)

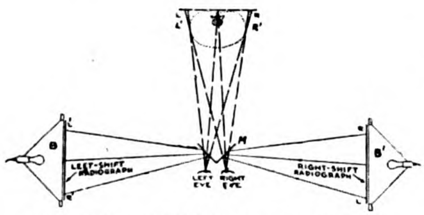


FIG. 172. VIEWING STEREORADIOGRAPHS.

The method of viewing stereoradiographs is somewhat different procedure than that of ordinary radiographs. The two stereoscopic radiographs are mounted over the illuminators of a Wheatstone stereoscope, shown in Fig. 171, and viewed through two plane mirrors. The method of visualization is illustrated in Fig. 172. Two illuminators, B and B′, are arranged on carriers that slide in a horizontal plane over two rails in the bringing of the two images into exact register. The two viewing mirrors M, set at right angles to each other, and each making an angle of 45 degrees with the plane of the corresponding radiograph, are mounted midway between the two illuminators and can be slid back and forth for focusing the superimposed images.

In order to effect exact orientation, the radiographs should be mounted in reversed aspects to each other, as shown at RL and R′L′ in Fig. 172, since a further lateral inversion will be effected by the mirrors in the superposition of the two images. A convenient way of realizing the exact superposition of the two images is to place a lead cross near one corner of the cassette changer during taking the radiographs.

During examination, when the observer places his head close to the mirrors so that one eye looks into each mirror, each eye receives a different view, and the combined images are seen standing out in stereoscopic relief. The impression perceived of the resultant image corresponds to what the eyes would have seen if placed at the two positions, during the exposures, of the focal spot of the X-ray tube. The two radiographs as viewed by means of the stereoscope will occupy the same positions with respect to the eyes as the film from the standpoint of the X-ray tube in the two positions.

Since the interpupillary distance is assumed as approximately 2.5 inches (2-9/16 inches, to be more exact), the best displacement of the tube target should closely correspond to this figure at an optimum anode-film distance of 25 inches. This means that with an exposure at 25 inch target-to-film distance the corresponding tube shift will be 2.5 inches. For a greater target-film distance provision should be made in the tube shift to precisely correspond to this variation. Furthermore, it is of considerable

importance that in the visualization of stereoradiographs the eye-image distance be the same as that used between the target and the film in making the exposures. The proper tube shift for various target-film and eye-image distances are given in Table XI.

It must be remembered that stereoradiographs made with the horizontal tube shifts should be mounted, for viewing, in the upright position, whereas those made with the vertical tube shift should be so mounted that the image will appear as if the subject is lying on his left side. In either case, to obtain the best interpretative result from stereoradiographs, a concentrated study must be directed to the center of interest; and, the more extended the examination the greater the stereoscopic effect becomes.

9. Immobilization In Radiography.—While making a radiograph, the immobility of the area of interest is essential to the delineation of sharp detail in the resulting image. We have already seen that U_m, unsharpness due to movement, is an inverse function of the stability of the part to be radiographed — the more stabilized the part, the less blurred is the radiographic image, all other factors remaining constant. The immobilization of the part may be effected by obviating the conditions causing vibrations of the X-ray equipment on which the part is positioned; by adequate immobilization of the part by means of compression bands, sand-bags, clamps, or towels held taut over the part; by correcting the conditions of discomfort of the patient's part arising from its being inadequately positioned; by having the patient suspend respiration during the exposure; and, by using, in the case of radiographs of the viscera, such as the chest, or heart, where involuntary movement can not be restrained, a high milliamperage (500—1000 M.A.) so as to shorten the time of exposure materially. Fine-focus rotating-anode tubes carrying as high as 1000 milliamperes have been developed, which permit exposures as short as one impulse or 1/120th of a second. Definition of good detail, due to decreased degree of movement of the part, combined with the advantage of a fine-focus tube becomes possible with the new development.

Co-operation of the patient in immobilizing the part with the least degree of discomfort must be sought at all times. The radiologist's thorough technical knowledge of the correct exposure factors and their adequate applications so as to employ the shortest exposure technic with the finest focal-spot consistent with the load factors applied to the tube commend special importance in the realization of the ultimate in the immobilization of the area of radiographic interest.

QESTIONS ON CHAPTER XVIII

1. (a) Of what importance is the study of optical principles as regards the propagation of X-rays?
   (b) What relation is borne by the object-film distance to radiographic distortion?
   (c) Discuss the factors requisite to the obtaining of the least degree of magnification in the radiographic image.
2. (a) A patient, with a heavy plaster cast about his right shoulder, is placed on the radiographic table. Due to the thickness of the cast, the patient's shoulder stood 4 inches from the radiographic film. If the focus-film distance was 40

inches, what relative magnification would occur in the image?

(b) How may the tendency for the structures remotest from the recording surface be offset from superfluous enlargement?

(c) In the attainment of a radiograph with a high degree of interpretable features, what practical importance is held by the correct projection of the central ray to the area of exposure?

3. (a) What relation has the area of the focus to the definition of the image?

(b) At maximum focus-film distance, how is it possible to realize a reduction in exposure time to produce the optimum sharpness in the radiographic definition?

(c) What conditions are prerequisite to the securing of the optimum radiographic quality in an image?

4. (a) A chest, lodging a bullet and having a thickness of 8 inches, is placed against the radiographic table top and one inch from the fluoroscopic screen. If by shifting the X-ray tube equal distance from the center line the image of the bullet is displaced 4 inches while the shadow of an object located at the table top in the same line as the bullet moves 6 inches, locate the depth of the bullet from the surface in fluoroscopic aspect.

(b) A patient's part lodging a foreign body is placed against a fluoroscopic screen which is 22 inches from the X-ray tube. When the tube is shifted 4.5 inches to either side from the central position, the image moves through a distance of 3 inches. Find the depth of the foreign body from the fluoroscope.

5. (a) Of what advantage is a parallex method of localization of a foreign body?

(b) For determining the thickness of a water reservoir tank, the lead diaphragm of the X-ray machine is placed against the inside surface of the tank and its aperture is adjusted to 7 inches. The tank is radiographed, then, on a film placed in close contact with its outer surface, and the image indicates a magnification of 1.5 inches. If the distance between the inside surface of the tank and the tube target is 20 inches, find the thickness of the tank at this portion.

6. (a) In case two views at right angles can not be realized, what relative procedure must be undertaken to accomplish this purpose? Describe the technic.

(b) Why is it necessary to make a stereoradiographic exposure at an anode-film distance greater than 25 inches?

(c) Using Table XI, find the stereoscopic tube shift for eye-film distance of 28 inches, if the anode-film distance is 54 inches.

7. (a) Of what diagnostic importance are stereoradiographs?

(b) Discuss the quality of illumination most favorable for diagnostic interpretation of a radiograph.

(c) How may the exact orientation of the two stereoradiographs be effected for visualization?

8. (a) What relation has immobilization of the subject to the delineation of detail sharpness in a radiograph?

(b) What important place is held by the use of a rotating-anode X-ray tube in realizing the least degree of movement?

(c) Since involuntary movement of the viscera can not be restrained, what procedure must be followed in order to reduce unsharpness due to movement to a minimum?

CHAPTER XIX

PHOTOCHEMICAL EFFECTS OF X-RAYS

The first photographic method utilizing Gelatin-Silver Bromide plate is due to Maddox (1871). The scheme subsequently has been extended and modified in an endeavor to obtain increased sensitivity and finer gradation responsible for the quality of a radiographic film. The familiar darkening of the film upon exposure to visible light has achieved supreme practical importance in radiography, which employs light waves of extremely short wave-lengths in the form of X-radiation. Since the properties of the latter are of a distinct character the sensitive emulsion of the film must be radically different from that used in ordinary photographic films, viz., an X-ray film must respond to blue-violet fluorescence of the intensifying screens as well as being highly sensitive to X-rays. There is no known film emulsion, however, which is influenced by X-rays but not affected at the same time by visible light. A further distinction between a photographic film and an X-ray film is that the latter must be capable of recording slight variations in density of different tissues by providing adequate contrast, and proper definition.

The chief aim of modern radiography has been one of speed factor without sacrifice in quality of the radiograph. Several leading photographic manufacturers have been lately putting out radiographic products that are found to present the ultimate as far as the present-day knowledge of the chemical and physical nature of the photographic emulsion is concerned — speed, sensitivity, and exposure latitude, combined with uniformity of grains and freedom from defects are what responsible for the discriminate radiologist's going about his radiographic work with ease of mind and confidence. A great deal is contributed by the Eastman Kodak Company, indeed, to the progress and improvement in the quality of radiograph of the present-day films. Exposures which some years ago took several hours are now made in less than a second. For this latter condition, mention is in appropriate order, that the modern high-power X-ray tube together with ultra-speed intensifying screens have, however, contributed to a large extent.

1. The Radiographic Film.—The radio-sensitive emulsion of an X-ray film consists of a colloidal suspension of one of the three halogen compounds of Silver—Silver Bromide, Silver Chloride, or Silver Iodide. The emulsion is obtained by mixing a gelatinous solution of Silver Nitrate with Potassium Bromide in a dark room, which may be illuminated with a ruby glass photo-safety lamp. The chemical reaction of the two compounds is given as follows:

$$\underset{\text{(gelatinous)}}{AgNO_3 + KBr} \longrightarrow \underset{\text{(emulsion)}}{AgBr + KNO_3}$$

The resulting milky emulsion is cooled to jel; and, after having been washed with distilled water to remove all soluble salts, it is melted at a

gentle heat, and applied uniformly on both sides of a sheet of cellulose acetate base. When dry, each layer of the emulsion measures about 25 *microns* in thickness.

The sensitivity of an X-ray film may be increased by the presence of a small quantity of a sensitizer, such as uranine, eosin, erythrosin, quinoline red, rodamine, etc., in the Silver Bromide emulsion. The photosensitization to various intermediate wave-lengths between greenish blue to infra-red may be achieved by the following sensitizers in their respective order: Chrysaniline, eosin, cyanine or methyl-violet, nigrosine, dicyanin or neocyanin. The mode of action of these compounds in producing sensitization in the film emulsion is to influence the speed of blackening rather than the formation of the latent image.

A further dominating fact which has become recognized as exerting an influence on the sensitivity of the film emulsion is the size of its grains. The finer the grains of the emulsion relatively better the definition of the detail, but the film is less sensitive to the radiation. Emulsions having grains of diameters between 0.2 to 0.4 *micron* are over 20,000 times less sensitive than fast films containing grains having diameters between 2 to 4 *microns*. Moreover, the size of the grains, and hence the sensitivity of the film, can be increased by maintaining the colloidal silver emulsion for a few minutes at a temperature in the neighborhood of 100°C. This process, known as *"ripening,"* contributes to a large extent to the size and uniformity of the grains, and to the sensitiveness and exposure latitude of the emulsion.

2. The Latent Image.—Upon exposure of the film to X-rays, a photochemical change takes place in the silver halide in that an intrinsic image commonly known as *"latent image"* is produced in the sensitized emulsion. This change, which is not detectable to the naked eye, is attributed to the partial decomposition of the Silver Bromide to metallic Silver in presence of gelatin and light. Thus, the invisible impression is formed by the occurrence of ultramicroscopic particles of silver as *nuclei* or the *"centres"* around which other exposed grains of the emulsion are centeralized and become visible upon development of the film. The reaction may be given as

$$AgBr + \text{Gelatin} \xrightarrow{\text{Radiation}} Ag + \text{Brominated Gelatin.}$$

The tendency of a grain of Silver Bromide to be developed is dependent on the size of the grain and on the quantity of radiation received by it. Though larger grains are more sensitive to illumination, when different emulsions are compared, grains having the same size and shape may differ in their sensitivity. The grains are uniformly distributed in the sensitized coating, and their nuclei or centres increase in number with prolonged exposure. The development, however, starts from centres situated in the surface layers.

The quantity of silver liberated per unit surface in the process of exposure of the film to the radiation can be measured by the degree of blackening produced in the developed emulsion. The blackening is dependent upon the intensity, quality, and duration of the radiation, and upon the

quality and the extent of development of the film. Measured optically, the degree of blackening K may be expressed by the relation

$$K = \log\frac{I_o}{I} \tag{147}$$

in which, I_o represents the intensity of the incident radiation and I that of the transmitted radiation. The ratio of the first to the latter is called the opacity of the substance illuminated.

Alfter and Oosterkamp* in their investigation on "quality" of X-ray films have revealed that the blackening of the film (radiographic density) is a direct function of the exposure tension and that the exposure energy E is inversely proportional to the sensitivity of the film and also to the third power of the exposure tension, as shown by the following equation

$$E \propto \frac{1}{s.V^3} \tag{148}$$

where s is the sensitivity of the film and V the exposure tension.

3. Processing Of The Film.—The latent image produced in the emulsion of an exposed film renders the silver salt to become highly amenable to the action of a reducing agent, called *"developer,"* in which the image becomes further defined, by the liberation, from the radio-activated portions of the film coating, of grains opaque to ordinary light. The grains in the unexposed portions of the sensitive surface, however, remain unaffected by the action of the developer, and can be removed upon additional treatment of the film in another solution known as the *"fixer."* In the latter bath, the image becomes permanently *"fixed"*.

The processing of the exposed film consists of its treatment in the developer, rinsing in water, and its further treatment in the fixing bath, and finally, of washing, and drying. The result on the film is a radiographic image brought about by the chemical changes on the latent image effected by the radiation.

The following formulas, taken from the Book of Formulas, prepared by Eastman Kodak Company, disclose the ingredients of a typical developer, and a fixing bath, ideal for use especially in hot weather:

Elon-Hydroquinone Developer
(Formula D-11)

Water (about 125°F or 52°C)	500.0 Cc
Elon	1.0 Gram
Sodium Sulphite, desiccated (E.K.Co.)	75.0 Grams
Hydroquinone	9.0 Grams
Sodium Carbonate, desiccated (E.K.Co.)	25.0 Grams
Potassium Bromide	5.0 Grams
Cold Water to make	1.0 Liter

(Dissolve chemicals in the order given.)

*Fortschr. a. d. Geb. d. Rontgenstr., page 509, Vol. 55, 1937.

When used at 65°F (18°C) in either tray or tank, proper contrast will be given in about 5 minutes. If less contrast is desired, the developer should be diluted with an equal volume of water.

Chrome Alum Fixing Bath
(Formula F-16)

Solution A

Sodium Thiosulphate (Hypo)	960.0	Grams
Sodium Sulphite, desiccated (E.K.Co.)	60.0	Grams
Water to make	3.0	Liters

Solution B

Water (not above 125°F or 52°C)	1.0	Liter
Potassium Chrome Alum	60.0	Grams
Sulphuric Acid, C.P. (E.K.Co.)	8.0	Cc

(Dissolve the chemicals in the order given.)

Pour Solution B into A slowly while stirring A rapidly.

A fresh bath should be prepared frequently, because a chrome alum bath often loses its hardening properties in a few days either with or without use, while with an old bath there is a tendency for scum to form on the surface of the film. Any such scum, if present, should be removed by swabbing with cotton before drying.

The function of each ingredient taking part in bringing about the chemical change in the sensitive coating of the film is explained as follows: Elon and Hydroquinone act as reducing agents and convert the Silver Halide into metallic silver, as illustrated in the equation below.

$$AgBr + Elon + Hydroquinone \longrightarrow \underset{\text{(black)}}{Ag} + Bromide\ Compounds$$

It is this reduced metallic silver that gives rise to a change in color of the original emulsion from a straw to black or gray shade, which process reveals the latent image. Such a transition from a compound to one of elementary metallic form is favored in a mildly alkaline medium, and hence the use of Sodium Carbonate in the solution. Moreover, the latter compound renders the penetration of the solution into the interior of the film emulsion more certain.

The developer, due to its susceptibility to reaction with Oxygen from the air and thereby losing its proper strength in length of time, contains sufficient amount of Sodium Sulphite, which combines with Oxygen (to form Sodium Sulphate) more readily than the developer does, and, therefore, acts as a preservative of the latter solution.

Clean-cut gradations of black and white of the image are obtained by the presence of a small quantity of Potassium Bromide in the bath to yield Bromide ions that the action of the developer on the Silver Bromide is slightly retarded. Consequently, the reduction of the metallic silver occurs less violently and possible formation of chemical stain on the film is thus prevented. (See: Chemical Stains and Fog, Sec. 8.)

After the film is developed under controlled time and proper temperature, it is rinsed with water and immersed in the fixer for permanently

fixing the image by removing all unexposed silver salts from the emulsion. The presence of Sulphuric Acid in this bath is to suppress development at once by its acid reaction. Furthermore, in conjunction with Potassium Chrome Alum, Sulphuric Acid produces hardening of the gelatinous film surface.

Sodium Thiosulphate (Hypo) dissolves and removes all the unaffected silver salts from the emulsion; and, Sodium sulphite preserves the usefulness of the solution, which state comes to an end when the bath has lost its acidity. The latter is indicated when it requires for the mage to "clear" in a longer time than usual.

While the above formulas are some aid to the X-ray practitioner, in most instances it is more convenient to use prepared X-ray developer or fixer powders supplied by photographic concerns and recommended for use with their film. The content of each package is dissolved in a specific amount of water in accordance with instructions accompanying the package. Aside from eliminating the possibility of any error in measuring if bulk chemicals were used time is saved in mixing the contents. Because of the extra labor involved in measuring and mixing the ingredients from bulk chemicals, the extra cost, if any, of the prepared packages is offset by the convenience and the saving of time thus realized. Such packages may be procured from Eastman Kodak Company and other leading manufacturers of photographic supplies.

A new developer* recently put on the market is claimed to provide a fast-acting, uniform, stable solution, permitting the most accurate control over development. The standard development interval is only 3½ minutes at 65°F. If the film is developed for 5 minutes, the prevalent development period, a reduction of approximately 25% in exposure time may be allowed—a factor contributing to the longevity of the X-ray tube life.

The processing solutions are usually placed in tanks large enough to accommodate at least half-a-dozen of 14 x 17 films at one time. During treatment of the films in the developer, it is important that they be agitated from time to time, specially when first placed in the solution, to insure uniform development by removing the air-bubbles from the surface of the film. The process of agitation should be repeated while immersing the films in the fixer. This will hasten the arrest of development.

Agitation of the films in the respective solutions will be greatly simplified by using a film hanger. The procedure of attaching the film to the hanger is shown in Figs. 173, and 174.

Before the film is transferred from the developer to the fixer it should be well drained and then rinsed for at least 15 seconds to avoid transferring of the alkaline developer, retained by the film, to the fixing bath. If this precaution is not routinely observed the chemical balance of the fixer will be impaired, and stains may very likely result in the radiograph.

4. Standardized Time-Temperature Processing.—In order to be able to standardize an exposure technic, the exposed film should be developed for a definite interval of time and at a definite temperature. The normal developing time of a film is 5 minutes at 65°F., or 18°C. The film is fixed

**Kodalk X-Ray Developer*, obtainable from any Eastman Kodak Supply Houses.

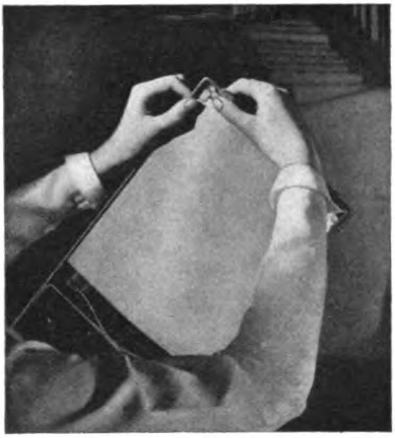


FIG. 173. ATTACH BOTTON CLIPS TO FILM FIRST.

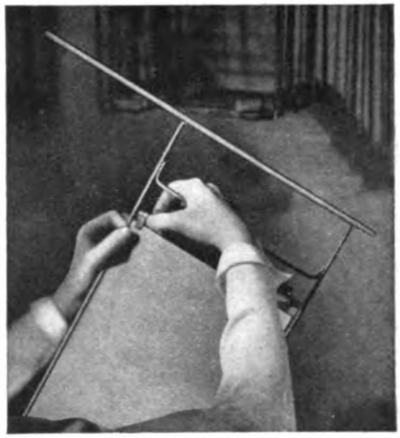


FIG. 174. NEXT. ATTACH TWO TOP SPRING CLIPS.

for at least 10 minutes in the fixing bath. Under these conditions, if the resulting radiograph is too dark to be of diagnostic value, then it can be considered that the film is either over-exposed or a high milliamperage is used; and, on the other hand, if the image lacks density, an under-exposure is indicated. Therefore, a standardized time-temperature processing becomes an assured measure in checking up on the correct radiographic factors.

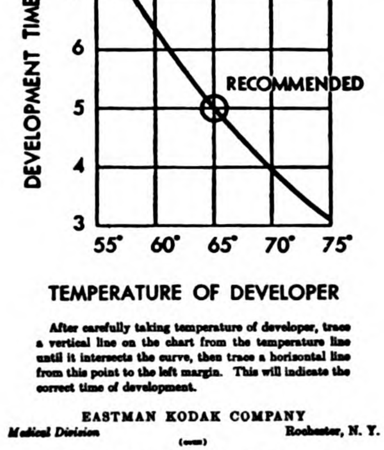


FIG. 175. EASTMAN TIME-TEMPERATURE DEVELOPMENT CHART.

By the use of Eastman Time-Temperature Development Chart, Fig. 175, correct co-ordination of the development time and temperature can be secured. If, for instance, the temperature of the developing bath is 70°F (determined by a thermometer), the time of development will be, according to the graph, four minutes. This is determined by mentally erecting a perpendicular from the 70° point to the curve and following horizontally from the point of intersection to the time ordinate, which, in the case under consideration, gives four minutes.

Since 65° appears to be the most favorable temperature from the standpoint of both chemical reaction and of preserving the firmness of the gelatinous emulsion, an electric automatic temperature controlling unit may be installed around the developer tank. The system renders an effective means of maintain-

ing a constant temperature at all weather conditions.

The above time-temperature values apply only to a developer of comparatively normal strength. As the developer becomes weaker by use, it will take a longer time for the image to appear. In such an event, charts, specially prepared for this purpose, may be consulted for proper development time. A relative time-temperature chart, prepared by Eastman Kodak Laboratories, for various strengths of the developing bath, may be secured from that concern without obligation. The graph applies, however, when Eastman films and processing solutions are used.

5. Reduction Of Dense Radiographs.—A dense radiograph is due to either over-exposure or over-development; and, when it is ascertained that a second exposure can not be made, due to the patient's inability to remain immobile (in the case of babies, older people, etc.), absence of the patient, or due to impossibility to duplicate the exact position of the area of interest in a second radiograph, etc., a high density radiograph can be corrected to a certain extent by reducing it in a clearing bath. To achieve this end, the film is wetted (if dry) by immersing it in water for a few seconds, and then placed in the reducing solution until the required density is obtained. It is then taken out of the solution and washed thoroughly to remove all traces of chemicals.

The simplest and easiest way is to use prepared reducer, which is obtainable in powder form with directions on the package. Each package is dissolved in a specified amount of water to be ready for use. But, when this is not available, a reducing solution can be prepared according to the following formulas emanated from Eastman Research Laboratories:

Farmer's Reducer (R-4a)
(For correcting over-exposed radiographs)

Stock Solution A		
Water	500.00	Cc
Potassium Ferricyanide	37.50	Grams
Stock Solution B		
Water	2000.00	Cc
Sodium Thiosulphate (Hypo)	480.00	Grams
For use take:		
Stock Solution A	30	Cc
Stock Solution B	120	Cc
Water to make	1000	Cc

(Add A to B, then add the water. Stir well.)

Pour the mixed solution at once over the radiograph to be reduced. Watch closely. The action is best seen when the solution is poured over the negative in a white tray. When the radiograph has thus been reduced sufficiently, wash thoroughly before drying.

Since this reducer decomposes rapidly, the two component solutions should be mixed just previous to use.

Farmer's Reducer (R-4a) also may be used as a two-solution formula by treating the dense radiograph in the ferricyanide solution first and subsequently in the hypo solution. This method has the advantage of giv-

ing almost proportional reduction and correcting for over-development, whereas the first method (single solution) gives only cutting reduction and corrects for over-exposure.

When radiographs are lacking brilliance due to the effect of secondary radiations or of a higher temperature development, the film may be improved by treating it in a clearing bath (Eastman Formula R-8) at 65° to 70°F (18° to 21C°) for from 1 to 10 minutes—the time depending upon the extent of clearing desired. If the effect of secondary radiation is not pronounced, 2 minutes treatment is considered to be sufficient. The films, however, should be thoroughly washed before and after clearing to remove all adherent chemicals from the emulsion.

Modified Belitzski Reducer (R-8)
(For correcting over-exposed and over-developed radiographs)

Water (about 125°F, or 52°C)	500.00	Cc
Ferric Chloride, Crystals	25.00	Grams
Potassium Citrate	75.00	Grams
Sodium Sulphite, desiccated (E.K.Co.)	30.00	Grams
Citric Acid	20.00	Grams
Sodium Thiosulphate (Hypo)	200.00	Grams
Water to make	1000.00	Cc

(Dissolve chemicals in the order given.)

The preceding formula is especially recommended for treatment of dense, contrasty radiographs. Since this reducer is the only known single solution of excellent keeping characteristics, it may be prepared in a tank of proper size and placed adjacent to the fixing bath; and, films, after having been taken out from the fixer and thoroughly rinsed, may be placed in this bath, as a routine procedure, to improve their radiographic quality. If a slower action is desired, the solution may be diluted with equal volume of water.

Some X-ray practitioners find it to their advantage to exercise a slight over-exposure in taking dental radiographs in order that the desired density of the film may be brought out by treating it in a clearing bath. The verity of such a procedure, however, is left entirely to the discretion of the technician, since a radiograph made with proper technic need not be subjected to such processes.

6. Intensification of Light Radiographs.—While the need for intensifying radiographs is seldom met, where necessary the density of the radiograph may be increased by treatment in an intensifying solution, such as given below.

Mercury Intensifier
(Eastman Formula In-1)

Potassium Bromide	22.50	Grams
Mercuric Chloride	22.50	Grams
Water to make	1000.00	Cc

The radiograph is bleached in the above solution until it is white, then thoroughly washed to remove all traces of adherent chemicals. The emul-

sion is then blackened with any one of the following solutions:

(1) A 10% Sodium Sulphite Solution.
(2) Developing Solution (diluted 1 : 2).
(3) 10% Ammonia (1 part concentrated 28% ammonia to 9 parts water).

After the desired density is obtained, the film is washed thoroughly and set aside to dry.

Another solution which is the only known intensifier to give an image of neutral color may be prepared as follows:

Silver Intensifier
(Eastman Formula In-5)

Stock Solution No. 1
- Silver Nitrate, Crystals (E.K.Co.) .... 60.0 Grams
- Distilled Water to make .... 1000.0 Cc

Stock Solution No. 2
- Sodium Sulphite, desiccated (E.K.Co.) .... 60.0 Grams
- Water to make .... 1000.0 Cc

Stock Solution No. 3
- Sodium Thiosulphate (Hypo) .... 105.0 Grams
- Water to make .... 1000.0 Cc

Stock Solution No. 4
- Sodium Sulphite, desiccated (E.K.Co.) .... 15.0 Grams
- Elon .... 24.0 Grams
- Water to make .... 3000.0 Cc

To prepare the intensifier, take
Solution No. 1 .... 1 part
Slowly add to this
Solution No. 2 .... 2 parts
Shake or stir to obtain thorough mixing. The white precipitate which appears is then dissolved by the addition of
Solution No. 3 .... 1 part
Allow the resulting solution to stand a few minutes until clear. While stirring, add
Solution No. 4 .... 3 parts
Stir thoroughtly.

The intensifier is then ready for use, and the film should be treated immediately. The degree of intensification obtained depends upon the time of treatment which should not exceed 25 minutes. The progress of the intensification may be followed visually and arrested at any stage.

After intensification the film should be immersed and agitated for 2 minutes in a plain 30% hypo solution and then washed thoroughly.

The mixed intensifier is stable for approximately 30 minutes at 70°F. (21°C.). To obtain most satisfactory results, therefore, the radiograph is treated within this period.

Wherever intensification or reduction is necessary, it is best to give the films such treatment immediately after they have been washed. Much

time is saved, and the radiograph, when dry, is ready for diagnostic examination.

Precautions:—Stains are sometimes produced during intensification or reduction unless the following precautions are observed: (1) The radiograph should be fixed and washed thoroughly before treatment and be free of scum or stain. (2) It should be hardened for 3 minutes in the formalin hardener (SH-1), rinsed, and immediately immersed for 5 minutes in a fresh acid fixing bath before the intensification or reduction treatment. (3) Only one radiograph should be handled at a time and it should be agitated thoroughly during the treatment. Subsequent to the treatment, the radiograph should be washed thoroughly and all water droplets drained carefully before setting it aside to dry.

Formalin Hardener (SH-1)

Formalin (40% formaldehyde solution)	10.00 Cc
Sodium Carbonate, desiccated (E.K.Co.)	5.00 Grams
Water to make	1000.00 Cc

Mix Well.

7. Processing Dental Radiographs.—The periapical dental X-ray films are processed in the usual manner, with the exception that special care should be exercised to hold the film on opposite edges, between the thumb and the forefinger, until they are placed on the developing hanger, shown in Fig. 176.

FIG. 176. PLACING DENTAL FILMS ON DEVELOPING HANGER.

To fasten the film to the hanger, one of the narrow edges of the film is inserted between the jaws of the clip and the latter is pressed together. After all the films are thus placed on the hanger, it is immersed in the developer for five minutes at 65°F., rinsed in water, and then placed in the fixing bath until cleared. The films are thoroughly washed and dried on their hanger before they are ready to be mounted.

One manufacturer* has recently perfected concentrated processing solutions which offer time-saving convenience along with qualities characteristic of usual prepared chemicals. The solutions are obtainable in 1 quart bottles; and, for use, the concentrated developer is diluted with three parts of water, while the fixing bath is prepared by diluting the concentrated fixer with three parts of water and adding the concentrated hardener (accompanying the fixer) according to the directions borne on the bottle. The use of concentrated solutions becomes of particular advantage in X-ray laboratories where small quantites of processing solutions are required.

8. Faulty Radiographs—Markings, Stains, Artefacts, etc.—Many of the faulty radiographs are caused as a direct result of not strictly observ-

*Available through Eastman Kodak Company.

ing the rules given under "*processing of the films.*" Negligence of a check up on an exhausted fixing bath may lead to difficulties that may cause needless waste of time and unnecessary annoyance until the condition is discovered and duly remedied.

Brown Stains:—Mention has already been made that after the film is taken out of the developer it should be rinsed in water for at least 15 seconds before it is immersed in the fixing bath. This removes the alkali solution from the surface of the emulsion. If this procedure is not followed carefully that the film, after having been removed from the developer, is directly immersed in the fixer, a considerable quantity of alkali from the developer retained by the film will be carried to the acid fixing bath; and, after sufficient amount of the alkali solution is thus transferred in the fixer, the fixing power of the latter will be impaired by having lost its acidity. When a film is fixed in such a bath, a brownish stain will result in the radiograph. This may arise also from incomplete fixation, lack of agitation of the films, chemical reaction between the developer retained on the film (which is not rinsed in water) and the fixer, and permitting the film to touch the side of the tank or to the surface of an adjacent film during development, Fig. 177. Therefore, care should be exercised to sustain the film at all times in free suspension in the tank. Moreover, rinsing the film after development should never be omitted, and that a stale fixing bath should never be used.

FIG. 177. PARTIAL IMAGE DUE TO CONTACT WITH ANOTHER FILM OR TANK DURING DEVELOPMENT, FAILURE TO DIRECT CENTRAL RAY, OR TO FILM NOT HAVING BEEN ENTIRELY IMMERSED IN DEVELOPER.

Liability of other markings to form on the radiograph is due to spattering of developer, exposure of the film to radiosensitive substances, and static electric discharges, formed by friction of the film with some other object, such as the hand, cassette, or the exposure holder.

Finger prints through careless handling of the film, and holding the film before the safelight for inspection for a prolonged time while still in process of development are some of the other causes contributing to the impairment of the radiogaphic quality.

Dichroic Fog:—This is characterized by the peculiar green appearance of the film when viewed by reflected light, and pink by transmited light. Fog is usually due to the accidental exposure of the film to ordinary light, X-ray radiations, or emanations from radio-active substances. Developing a film at higher temperatures than that specified; placing a film in a fixing bath whose acid content is exhausted; or, if the film is not thoroughly rinsed before it is transferred to the fixing bath from the developer, a chemical reaction between the developer on the emulsion and the silver yielded in the fixer from previous films may occur; and, as a result, each one of these factors may contribute to the formation of the

*Dichroic refers to the property by which light transmitted through a crystallized body is exhibited in various colors according to the direction of the incident beam.

effect. It should also be kept well in mind that out-dated films should never be put into radiographic use, to eliminate by far the annoyance due this phenomenon, Fig. 178.

Artefacts:—Frequently it becomes desirable to scribe lines on the Potter-Bucky diaphragm top for accurate positioning of a part of the subject. In such an event, care must be exercised that the lines are not filled with a material (usually paint) offering opacity even to a very small degree to X-radiation. Furthermore, excessive depth in scribing in the top made of any such material as wood, aluminum, bakelite, or fibre, must be refrained from; and, if deep lines have already been drawn, they must be filled with wax, paraffin, or any other radio-transparent material to compensate for the density at these reduced portions. Failure to observe this condition may result in the appearance of artefacts in the radiograph which may be misinterpreted for a fracture. The delineation becomes more pronounced with increased target-film distances.

FIG. 178. THE EFFECT OF FOG ON A RADIOGRAPH.

Other serious diagnostic errors may arise as a result of negligence to clean the inner surface, especially the point, of a dental cone from time to time. In Fig. 179 is a dental radiograph which shows a clear, irregular area representing the shadow of a particle of lead glass chipped off the lead-glass shield of the X-ray tube and fallen into the point of the cone. This could be easily misinterpreted as a filling in the tooth, or as a foreign body in the gum.

Excessive Swelling of Emulsion:—The condition is due to processing the film at temperatures higher than those recommended, or to the use of an exhausted fixing bath.

The radiograph reproduced in Fig. 180 exhibits a reticulated appearance with fine lines in irregular pattern. Only way to curb the repetition of the effect is to maintain a standardized temperature throughout the developing, fixing, and washing of the radiograph.

FIG. 179. ARTEFACT IN IMAGE.

FIG. 180. RETICULATION OF THE GELATIN DUE TO WARM WATER BATH OR DUE TO A COOL FIXER.

9. General Processing-Room Considerations.—It is desirable that a processing room be of ample size and that it be located near the exposure room. If space permits, access should be by a light-lock; otherwise, an inside lock should be provided to prevent the opening of the door by any person from the outside while the films are being handled in the room.

Isolated from the processing tanks, a bench, for loading and unloading exposure-holders, cutting unexposed films, marking and fastening films on film-hangers, should be situated preferably on the opposite side from the processing tanks to avoid the risk of inadvertently wetting the films, intensifying screens, etc.

Underneath the bench, on one side, provision of a bin must be made for storing a supply of films, and on the other side, of an electrically-controlled film-drying cabinet. On the wall above the bench there should be convenient facilities for keeping different size film hangers, and a safe light suspended from the ceiling to illuminate the top of the bench, Fig. 181b.

Particular convenience is offered by the incorporation of a film-transferring cabinet in the wall between the loading bench and the radiographic room. Such a cabinet eliminates the inconvenience of carrying the exposure holders in hand from one room to the other. Due to a safety lock mechanism, the cabinet can not be opened from either side while the door at the opposite side is open. The scheme prevents light or X-radiations entering the dark room by way of the cabinet compartment.

It is, indeed, very essential that the processing room be absolutely light-tight, which condition instigates the necessity of a constant circulation of fresh air in the room. This end may be achieved by the installation of one or more motor-driven ventilators set in the upper part of the wall on a convenient side.

Observance of scrupulous cleanliness is of first importance in the attainment of most satisfactory radiographic processing conditions. This includes the washing of the hangers, and thermometers, immediately after use, and thoroughly wiping the top of the bench and cleaning the floor before leaving the room. The procedure not only aids the prevention of the contamination of the processing solutions, and soiling of the films during handling, but promotes, in the room, hygienic conditions so important for the health and well-being of the individual occupying the room throughout the day.

Since dry radiographic films are more sensitive to light than when they are wet, a proper amount of indirect illumination of photographically safe quality should be provided so that the films may be handled with safety. Such an illumination should be of pleasing tone so that the eyes can easily adapt themselves.

There are a number of commercially obtainable safelight lamps. Of these, Wratten[1], Eastman[2], and Kodak[3], safelight lamps, Figs. 181a, and 181b are considered to provide the maximum illumination with minimum danger of fogging the films when inadvertently exposed to the radiation from these lamps. The Wratten Safelight, series 6A or series-1, is so designed that it permits the dry X-ray films to be exposed to its light at a distance of three

[1,2,3]Available through Eastman Kodak Company.

PLATE V

(COURTESY EASTMAN KODAK COMPANY.)
MODEL DENTAL RADIOGRAPHIC PROCESSING ROOM.

feet for one-half minute; at one-half feet, for approximately ten seconds. At greater distances, longer exposure to the safelight is permissible.

KEY TO PLATE V

1. Eastman Darkroom Ventilator.
2. Bar for holding intra-oral dental film developing hangers.
3. Eastman Dental Film Developing Hangers.
4. Eastman Safelight Lamp.
5. Brackets for holding extra-oral film hangers.
6. Eastman X-ray Film Developing Hangers.
7. Electric Fan.
8. Bar for holding hangers while drying films.
9. Drip pan.
10. Electric outlets.
11. Eastman Interval Timer, Model B.
12. Time-Temperature Development Chart.
13. Eastman Tank Thermometer.
14. Waste chute.
15. Eastman X-ray Tank Developing Outfit.
16. Sink, with mixing valve.
17. Bar for holding towels.
18. Lead-lined box for films.
19. Cassettes.
20. Eastman Engraved Graduates for measuring liquids.
21. Eastman Hard Rubber Stirring Rods.
22. Two 5-quart enamel vessels for mixing solutions.
23. Eastman Prepared X-ray Fixing Powders.
24. Eastman Prepared X-Ray Developer Powders.
25. Waste receiver.
26. Two 4-quart brown bottles for storing solutions.

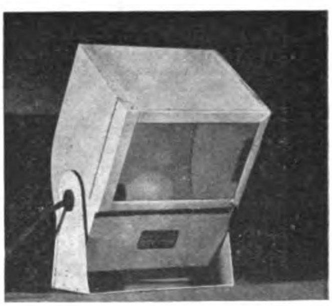


FIG. 181A. KODAK SAFELIGHT LAMP.

FIG. 181B. WRATTEN SAFELIGHT LAMP.

To obtain the maximum safety as regards the sensitive emulsion of the dry film, a safelight is usually suspended from the ceiling of the processing room. This renders the loading and unloading of the exposure holders quite safe. Another safelight is mounted on the wall several feet from the processing tanks to aid vision in the immersion and removal of the film from the respective baths.

The safety of the illumination from a safelight can be checked by partially exposing a dental X-ray film for varying lengths of time from a position near the loading bench where the films are usually handled. The illumination may be considered safe if no definite fog is indicated on the exposed portion after development.

As the gelatinous emulsion of the radiographic film softens under warm processing conditions, an automatic temperature controlling system should be installed around the tanks containing the processing solutions. The wash water should similarly be kept at a low temperature throughout the entire period of washing of the film, which process should not be prolonged more than 30 minutes under these conditions. A temperature of between 60° to 70° F. (16° to 21°C.) for washing is considered to be safe; but, if the water is at a slightly higher temperature, and there is ample circulation throughout the wash tank, a film may be washed for 15 min-

utes, as the gelatinous surface may soften considerably with prolonged washing at such a temperature.

For further convenience, a white light may be added for inspecting films while they are wet. The lamp may be conveniently supplemented by a foot-switch that the light can be turned on for the desired interval, leaving both hands free.

QUESTIONS ON CHAPTER XIX

1. (a) What photochemical advances mark the realization of "quality" factor in modern radiographic films?
   (b) Give the composition of the X-ray film emulsion pointing out the inherent characteristics responsible for its photosensitivity.
   (c) When different film emulsions are compared for sensitivity, what part do "centres" and the size of the grains play?
2. (a) Discuss exposure energy in relation to the exposure tension, and blackening and sensitivity of the film.
   (b) How does the latent image render the silver salt of the emulsion to become amenable to the action of a reducing agent? Discuss photochemical effects in this connection.
   (c) State the steps in the processing of an exposed film.
3. (a) Give the ingredients of a developer, and of a fixer, and then state the function of each chemical in the respective solutions.
   (b) Of what radiographic value is the standardized time-temperature processing?
   (c) Using the chart in Figure 175, find the development time if the temperature of the developer is 67°F.
4. (a) Explain why 65° F is the optimum temperature for development.
   (b) To what factors is the over-density of a radiograph attributable? How can a distinction be made of the conditions producing this effect?
5. (a) How can a high density radiograph be corrected?
   (b) State the differences between the Farmer's reducer and that of Belitzski in their actions on the radiograph.
6. (a) What precautions are essential preparatory to treating a light radiograph in an intensifier?
   (b) Give the procedure for processing periapical dental X-ray films.
   (c) What factors render anticipation on brown stains in a radiograph?
7. (a) If a film has undergone development at a high temperature, or, if it is transferred to the fixing bath without having been rinsed, or, if it is an out-dated film, what extraneous effect may be expected in the resulting radiograph?
   (b) Enumerate preventive measures in producing a radiograph free of artefact.
   (c) What tendency is indicated by an exhausted fixing bath on the radiographic emulsion?
8. (a) List the equipment and state the conditions essential in an efficient processing room.
   (b) Explain why a red or green safelight does not appreciably affect the emulsion of the film.
   (c) To what extent is a dry unexposed film susceptible to the illumination from a safelight?

CHAPTER XX

ELECTRICAL SAFETY AND X-RAY PROTECTION

The problem of complete electrical and X-ray protection from a practical standpoint has long been the object of X-ray engineering, and research toward this end has been extended throughout the laboratories the world over, until the search fundamentally has terminated with the introduction of the first commercially available ray-proof tube by Philips Metalix Corporation in the year 1927. The new development is further supervened, in the following year, with the incorporation of a grounded metal sheathing around the entire X-ray tube to offer the advantage of absolute protection against high tension hazards. Following this trend, practically all X-ray tubes of modern manufacture are provided with protection against both the high-tension and stray radiations from the X-ray tube.

Prior to recent introduction of modern safety on standard X-ray equipments, various protective devices, such as sheet lead, plumbized rubber aprons and gloves, lead-glass shields partially surrounding the X-ray tubes, and lead-glass protective screens, were supplied with every X-ray machine by the manufacturer. But, such means did not fully warrant the necessary safety of the operator, or the patient, since serious damages by accidental contact with the high tension lines or by excessive exposure to X-ray radiation were casually reported as having occured. Hence, the necessity for limiting the situation to the confines of absolute electrical and X-ray safety has given impetus, with the co-operation of the International X-Ray and Protection Committee with manufacturers of X-ray equipment, to the gradual but steadily advancing development of the ultimate protective measures.

1. Electrical Safety Measures.—Whilst the electrical safety aspect of the question lends itself to the design, constructional detail, and material of the equipment built on the discretion of the manufacturer, the problem by no means is met with an easy solution; for instance, for the provision of a simple and practical tube shielding, which will afford, at the same time, an adequate system for dissipating the heat generated during the operation of the X-ray tube; for the installation of overhead aerials which will produce practically no corona discharge; for insulation of the X-ray personnel from ground by providing adequate floor covering; for efficiently grounding all independent electrical circuit systems, metal parts of the apparatus, etc.

Wherever possible, shock-proof X-ray equipment is highly recommended for the safety of both the operator and the patient. Distinctly indicating the main and supply switches by means of pilot lights or by some other readily distinguishable sign is found to be of aid in the elimination of electrical hazards. Push-button or foot-switch should be of such design as to make it incapable of accidental closure, and that the former should

be encased in vapor-proof receptacle for obviating the danger of readily inflammable anaesthetic gases.

Since exposed high voltage parts have the tendency toward generating gases, such as Nitrous Oxide, Ozone, etc., adequate ventilation should be provided in order to maintain a hygienic condition among those concerned in the X-ray room.

(*a*) *Grounding The X-Ray Primary Circuit* (*or Control Unit*).—The control handles of all X-ray units are invariably of insulating material so that electrical contact with live studs or metal parts is practically impossible (provided, of course, that the insulation is not worn down to the metal core). In addition to the provision of insulations surrounding the control knobs all flexible conductors used in the low tension circuit of the apparatus are adequately insulated with rubber sheathings. Since these are constantly subject to inadvertent handling, kinks may form at connection points, causing the insulation to become susceptible to breakdown and to exposure of bare wires, which may become a potent danger to human contact. The latter hazard may be reduced, however, by adopting small voltages for all control circuits from appropriate autotransformer tappings.

Earthing the X-ray primary circuit produces a material reduction in electrical hazards but such must not be regarded as absolute immunity to electrical shocks. The condition is one of diminution in the magnitude of shock (if such be received) and can not be pre-determined whether or not it will meet with fatal consequences.

If an earthed X-ray control unit is installed permanently in an X-ray operating room having a floor of high insulation characteristics, the condition may be regarded as one also insulating the operator from ground. When such is the case, the operator is reasonably safe in accidentally touching a live lead from any part of the control unit. However, the fact that the control panel is suitably grounded does not warrant the operator at the controls an absolute exemption from electrical shocks in case he makes a simultaneous contact between a live lead from the unit and an earthed object.

(*b*) *Protective Measures In X-Ray Secondary Circuit.*—As the secondary circuit of an X-ray transformer is sustained, during operation, at a high potential, the condition becomes a potent source of danger wherever there is a possibility of accidental contact with a live conductor. Contrary to common belief, the effect is not always the more dangerous the higher the voltage, as fatal consequences as a result of contact with voltages as low as 40 volts are reported as having occurred. Hence, no conclusion can be drawn with reference to safety limits of potential. It is true, however, that a direct or constant potential current is more dangerous than a pulsating or an alternating type. In general, a high frequency current is less dangerous than a low frequency energy. In this connection it will be further noted that a transformer associated with pulsating rectified currents, such as produced by a mechanical rectifier or by valve-tube alone is more dangerous than that connected across a rectifying set employing condensers in conjunction.

X-ray practice in this country requires the embodiment of a ground lead generally at the center of the high-tension transformer secondary.

The scheme aims at reducing the risk of a high voltage electric shock on the assumption that smaller tensions would be safer to guard against. Since, by grounding the secondary in the middle each of its two divided sections develop half the entire transformer potential that the X-ray tube having its terminals not provided with high-tension protection may be positioned closer to the patient. This, of course, does not actually prevent a flash-over from occurring but affords the insulation of the patient to ground for only half the voltage of the transformer. With latter provision if a flash-over occurs the patient receives a shock which would only produce a slightly uncomfortable feeling. It is, however, unlikely that a patient is completely insulated from earth, since most X-ray apparatus are rendered a ground potential by intentionally earthing the table and the tube stand.

Fundamentally a transformer winding may be grounded in only one place, and usually no current will flow in a ground wire. But, when a second connection with the ground is established, the portion between the two ground leads will be rendered short-circuited, and a heavy current will flow to the ground. Summed up, this means that in the event of a person coming in contact with the non-grounded secondary of a high-tension transformer, that person will experience no shock, as, by doing so, he will merely establish grounding of the circuit at that point. If, however, a simultaneous flash-over from some other point of the transformer to the ground (to grounded X-ray tube or its stand) occurs, the person will receive the full potential difference developed between the two grounded contacts. Accordingly, a non-grounded secondary must be insulated for the full potential difference sustained across the X-ray tube. This is especially true for high-voltage cascade circuits.

On the other hand, in Europe transformer grounding does not lend itself to common practice, but the transformer itself is heavily insulated from ground with the mere idea that no shock could be obtained if anyone came accidentally in contact with a transformer or tube terminal. So long as everything remains normal at the transformer winding the scheme would appear quite feasible. But, if a ground contact is made at one end of the X-ray tube (as by touching) the potential at the other terminal will rise, and should a flash-over from the tube to the tubestand occur, or should a sudden breakdown take place in the insulation of the transformer as a result of previous slow leakage, the subject then becomes liable to receive a shock of the entire applied tube potential. Here, again, the scheme is confronted with pertinent disadvantages.

There are a good many commercially available safety devices for the purpose of switching off the supply current to the X-ray generator should an accidental human contact occur with the high tension circuit. Of these, various types of electrosensitive relays, tripping gears, automatic circuit breakers etc.—some furnished in conjunction with visual or auditory signal means to give warning prior to actual contact—have been used for many years with satisfactory performance to some extent. A French product by Pilon employs a sensitive relay whose electromagetic winding is in series with the center ground lead of the high-tension transformer secondary. During normal operation of the transformer this lead is at ground potential, and, therefore, no current flows through the relay wind-

ing. But, when an accidental connection is made between any portion of the high-voltage circuit (excepting the center grounded point of the transformer) and the ground, the relay immediately becomes energized, and, in turn, actuates a circuit breaker connected in the primary circuit of the X-ray transformer, thus shutting off the current to the high-tension circuit. The device is designed to minimize the effect of the contact with high voltage and can not possibly prevent its occurrence. Furthermore, this should be frequently tested for proper performance by substituting a 100,000-ohm resistance for human contact ground.

The impetus in the manufacture of modern X-ray equipment, however, is given to the production of an apparatus which makes dependable safety provision where the possibility of an accidental or intentional contact with any live conductor in the system is precluded. Full protection against high tension is achieved by immersing the transformer in an adequately grounded vessel filled with oil, by completely surrounding the X-ray tube with a grounded metal casing, and by providing heavily insulated flexible cables for making connection between the high-tension transformer and the X-ray tube. The instrument panel, the control handles, and the stand are well insulated. Further protection is offered through grounding the X-ray table, which procedure eliminates the possibility of the accumulation of electrostatic charges on the apparatus due to the surrounding ionized air. It is only through closely adhering to the enforcement of the application of these safety provisions that the ultimate electrical protection in practical X-ray work is assured.

2. X-ray Protection.—Reference has already been made as regards some physical, and chemical, effects of X-rays when absorbed by matter. It has been further indicated that X-rays have definite influence upon living cells, that moderate dosages may actuate various physiological functions while excessive amounts tend to produce necrosis of the cells irradiated. On this latter concept is based the treatment of carcinous tissue in that the process of the life-cycle of the malignant cell is accelerated so that cellular degeneration is brought about as the expected end result. The application of roentgen rays to producing sterility in human beings by rendering the germ cells infertile has been widely used by roentgenologists, but the condition has been only temporary. The offsprings of the parent organism, who has become subject to such treatments, have generally not survived with normal characteristics.

Table XII:—Relative Sensitivity Of A Normal Tissue to Radiation Of Medium Hardness. (Hirsch)

Leukoycytes:
- 2.5 Lymphocytes
- 2.4 Polynuclear

Germinal Cells:
- 2.3 Ovarian
- 2.2 Testicular

Blood-forming organs:
- 2.1 Spleen
- 2.0 Lymphatic Tissue
- 1.9 Bone Marrow

Endocrines:
- 1.8 Thymus
- 1.7 Thyroid
- 1.6 Adrenal

Blood Vessels:
- 1.5 Endothelium (intima)

Dermal Structures:
- 1.4 Hair Papillae
- 1.3 Sweat Gland
- 1.2 Sebaceous glands
- 1.1 Mucous Membrane
- 1.0 Skin
- 0.9 Serous Membrane

Viscera:
- 0.8 Intestine
- 0.7 Liver, Pancreas
- 0.6 Uterus, Kidney

Connective Tissue:
- 0.5 Fibrous Tissue
- 0.4 Muscle, Fibrocartilage
- 0.3 Bone
- 0.2 Nerve Tissue
- 0.1 Fat

Indiscriminate exposures to X-rays may lead to erythematous effects in the skin or in the deep-lying structures, depending upon the degree of penetration of the radiation. The effective wave-length of the latter is the chief determinant as to whether the necrotic reaction will occur in the peripheral or in the deeper tissue structures. Polymorphonuclear cells exhibit the most radiosensitive characteristics whereas nerve and fat cells are affected the least by X-rays, as will be noted in Table XII.

The radiation renders the nuclear membranes of the living cells more permeable to the absorption of water that the dilution of the cell plasma with the resultant diminution in its concentration and osmotic pressure are brought about. The condition gives rise to hemolysis in erythrocytes (red blood cells) with consequent low blood pressure and enemia, and to leucopenia by lowering the number of leukocytes (white blood cells). Further symptoms of X-ray injury are indicated in the constriction of the capillary vessels, inhibition of enzymatic secretion, increase in hydrogen-ion concentration, retardation of the glandular functions and of the division and growth of embryonic cells, disintegration of the cells constituting the hair follicles, desquamation of the epithelial cells, etc. The skin and the genitals are extremely sensitive to X-rays. (For therapeutic effects of X-rays, see Appendix VI.)

Since the effect of X-rays is cumulative, impunity of those who are exposed daily to the radiation is impossible. Moderate exposure to X-rays is not harmful, but overexposure may result in desquamation (X-ray burns) of the superficial structures followed by severe dermititis. In more advanced cases of the disease carcinous ulcerations or sloughing of the deep-lying structures may occur. The condition is extremely painful, and unfortunately there is no known remedy to cure or even to temporarily arrest the progress of the disease, which ultimately leads its victim to his grave. If, however, the condition in the case of superficial structures is not far advanced some relief may be obtained by exposing the affected area to long-wave ultra-violet rays in gradually increasing doses.

(*a*) *X-Ray Protective Means.*—While with modern X-ray equipment practically it is impossible to contract acute injuries from X-rays, with the case of older type of apparatus the operator appears to be constantly menaced by a tendency to undue exposure to X-rays. Since some of the older equipments are not adequately protected from X-rays, negligence of the operator to screen himself from the radiation field by means of lead screens, lead-impregnated aprons and gloves, etc., the danger of X-ray "*burns*" is ever prevalent. The "*burns*" are produced principally by the absorption of long-wave (soft) X-rays constituted partially by direct radiation from the tube and partially by secondary radiations. The former group may be easily screened off by providing adequate ray-proof shielding about the entire length of the X-ray tube with the exception of the port of emergence of the useful radiation.

In the older type apparatus lead-glass bowls partially precluding the X-rays from the operator as well as from the patient are still in use as protective means against X-rays. For fluoroscopy, further safety may be insured by providing the fluorescent screen with a lead-glass of a thick-

ness not less than one-quarter inch. In radiography, however, adequate X-ray protection from an unshielded X-ray tube can be obtained for the operator by a lead screen 3 mm thick, or by its equivalent (lead-impregnated rubber—12 mm, or lead-glass—20 mm.)

(*b*) *Permissible X-Ray Dose.*—While in recent years darangement of health instituted by cumulative effects of exposures to small doses of X-rays are rarely met, nevertheless the subject of permissible X-ray dose can not escape the attention of the layman who is constantly seeking to collect comprehensive data as regards the dreaded effects of X-rays on organic system in an attempt to adopt increased precautionary measures to minimize the dangers that are attendant as a result of undue exposure to the radiation.

Though data regarding the amount of radiation to produce harmful effect is meagre, due to varying radiosensitivity of different individuals, the proposed permissible dose (*tolerance dose*) that can safely be absorbed without producing ill effects in the human body ranges from 0.2-r to 0.288-r per square centimeter of the body surface per day of 8 working hours.* The estimates are based on the consideration of dosage for producing a distinct reddening of the skin, or an erythema reaction. The amount of radiation to produce this reaction is known as one *skin erythema dose* (*HED*). In absolute units this is equivalent to 600r to 850r for high tension ranges, depending upon the physical disposition of the individual to X-rays and upon the voltage at which the radiation is incited. With the quality of radiation usually employed in medical radiography and fluoroscopy the *threshold erythema* is calculated as 300 to 320 roentgens.

Since absolute protection against X-rays is practically an impossibility, those engaged in X-ray work are constantly subject, to some extent, to exposure to disseminated radiation limited only by the protection afforded by the clothing worn and the area it covers. A convenient method of determining the radiation quantity received daily is the one that affords a qualitative measurement photographically on a film. The method further gives an index as regards the efficiency of X-ray protective power of the shield surrounding the X-ray tube. For either purpose, the operator may fasten a paper clip on a dental X-ray film packet and place several of these at various distances from the X-ray tube, also himself carrying one in his breast pocket, with the lead-lined surface toward his body, for a period of two weeks. If the developed film definitely shows the image of the clip surrounded by a definitely contrasty field, necessity for increased protective measures is indicated. With an average potential of diagnostic range, this blackening would be equivalent to 2×10^{-4} of an erythema unit or 0.04-r, using a Radia-Tized Eastman Dental Film for the test under consideration. If a recently-developed dosimeter is available the ionization method of X-ray intensity measurement will give a more accurate index of the stray radiation.

As regards the protection of the patient from excessive exposure, the commonly accepted safe exposure limit to a single area (except head) is

*Bureau of Standards, Handbook 15, as of 1940.

1200-M.A. seconds at a focal-skin distance of 15 inches, using an Aluminum filter of 1 mm thickness. This value is computed on the basis of X-rays incited by 100 Kv.P. (wave-lengths from .12 to .15 A.U.), and varies as the square of the distance.

With a focal-skin distance of, for instance, 25 inches, the permissible amount can be increased to 3400 M.A.-seconds. In the case of fluoroscopic work, where the target-object distance runs between 10 to 15 inches, or a little over, the permissible cumulative amount of radiation over a wide exposure field at 5 M.A. and about 75 KV is five minutes, while with lower milliamperages, for instance, 3 M.A., the exposure can be extended to approximately eight minutes, or even to longer period if the area of interest is constantly shifted for examination from different angles. An integrating device provided with an automatic cut-out may be used to advantage to stop further exposure in case the permissible time limit is exceeded. Under these conditions adequate protection of the patient is amply assured. It must be observed, however, that any single field irradiated with full exposure limit should not be subjected again to the radiation for at least three weeks.

Since diagnostic exposures are made at various focus-skin distances, and since the exposure limits are dependent on the intensity of the radiation, their values are determined by the inverse square law, viz., the exposure limits are varied inversely as the square of the focus-skin distance. The chart presented in Table XIII gives the safe exposure limits for all regions at various focus-skin distances. If the radiographic technic permits, it is advisable to always use a filter when radiographing any single area of the head, especially the regions covered by the scalp.

It will be strongly recommended that a chart of this type be available at all times in the X-ray operating room for ready reference of the operator. This will eliminate any subsequent regrets as a result of inadvertent use of X-rays upon patients as victims.

(c) *X-Ray Screening Powers Of Different Materials.*—In planning for building a new X-ray laboratory where a high-tension equipment is to be installed, it is of vital importance that special consideration be made for adequate protection of the personnel, the patient, and the radiographic films against disseminated X-radiations in the room. This protection may be assured by shielding the X-ray tube with X-ray insulating materials and further providing the operator with appropriate ray-proof aprons, gloves, screens, etc. Of these materials, lead offers a most effective screening, but because of other limitations, its application exclusively in all types of X-ray insulation has found demand only with reservations. The fact remains that it is more convenient, in certain types of X-ray screening (as in tubes with built-in X-ray protection, etc.), to use a mixture of lead compound, or a lead-impregnated material, to ensure an effective X-ray protection.

In the past, lead-glass screens and windows, open-type protective glass shield incorporated around the X-ray tube, and lead-impregnated rubber gloves and aprons, etc., have been used to protect the X-ray operator from receiving undue radiation; and, in therapy work, the generating apparatus has been completely enclosed by lead sheets of several mms in thickness. But, with modern equipment with built-in X-ray protection and electrical

Table XIII*:—Safe Milliampere-Second Exposure Values For Various Parts At Varying Focus-Skin Distances.

HEAD

Focus-Skin Distance	No Filter	½ mm. Al Filter	1 mm. Al Filter
8″	157	191	255
9″	194	264	324
10″	238	300	400
11″	292	363	484
12″	346	431	575
13″	405	507	675
14″	470	589	784
15″	540	675	900
16″	616	769	1025
17″	691	864	1152
18″	777	971	1295
19″	866	1083	1444
20″	964	1200	1600
21″	1059	1322	1762
22″	1159	1451	1935
23″	1269	1583	2115
24″	1382	1728	2304
25″	1502	1873	2502

ALL PARTS EXCEPT HEAD

Focus-Skin Distance	No Filter	½ mm. Al Filter	1 mm. Al Filter
8″	202	255	341
9″	259	324	432
10″	317	400	533
11″	389	484	645
12″	461	575	768
13″	540	675	900
14″	626	784	1044
15″	720	900	1200
16″	821	1025	1368
17″	922	1152	1540
18″	1037	1295	1728
19″	1152	1444	1920
20″	1282	1600	2136
21″	1411	1762	2352
22″	1548	1935	2580
23″	1692	2115	2820
24″	1843	2304	3072
25″	2002	2502	3336

*Reprinted from "X-Ray Studies III" by permission of the General Electric X-Ray Corporation.

safety such cumbersome procedures become obsolete for practical purposes in view of the unconditional flexibility of use afforded by the self-protected modern X-ray equipment.

The use of sheets of lead in lining the protective screens, the walls and floor coverings of the X-ray room, and the film storage cabinet, for X-ray shielding is still a common practice. But, where desirable, the walls and the floor of the X-ray room may be built with ray-proof materials other than lead itself. When employing such a material its protective power relative to lead must be taken into consideration. For instance, Barium Plaster affords a protection of approximately 1/10 of that offered by lead of same thickness. Therefore, the walls of the X-ray room may be plastered with a layer of this mixture of a thickness between 8 to 10 times that of lead necessary to provide adequate X-ray protection. In the case of brick or concrete walls, approximately 100 times the equivalent lead thickness is required to ensure the same protection. Kaye and Owen have determined the lead equivalent powers of some protective materials, which are included in Table XIV. It will be noted that the comparison of the different materials are made relative to 1 mm of sheet lead, and the source of X-rays is assumed as one from a Coolidge tube energized by a tension of 100 KV and producing limiting wave-lengths in the order of .12 A.U.

Table XIV:—Lead-Equivalent Screening Powers of Materials.

Material	Protective Power
Lead	1.00
Lead Rubber	0.25 – 0.45
Lead Glass	0.12 – 0.20
Bricks and Concrete	0.01
Woods	0.001
Barium Sulphate Plaster *	0.05 – 0.13
Steel	0.15
Brass[1]	0.25
Aluminum[2]	0.016

By use of equation (122), the X-ray protective power of any element may be calculated by first determining its thickness which will produce an equal diminution of the X-ray intensity as that obtained by employing 1 mm of lead at the same distance from the radiation source. It must be well kept in mind that the lead-equivalent relation of the different substances are constant and independent of the voltage applied to the tube.

The safety recommendations, as regards the minimum equivalent thickness of lead for adequate protection for various high-tension voltages, adopted by the International X-Ray and Protection Committee as in record in the National Bureau of Standards Handbook 15, and HB20, specify the following minimum thickness of lead equivalents as adequate shielding against radiations incited by given tube tensions:

*This mixture contains 3 parts $BaSO_4$ and 1 part Portland Cement.

[1,2]Author's insertion.

Table XV:—Minimum Equivalent thickness of Lead vs. Voltage.

X-Rays Generated By Voltages	Minimum Equivalent Thickness of Lead (mm)
Not in excess of 53 KV or 75 Kv.P.	1.0
Not in excess of 70 KV or 100 Kv.P.	1.5
Not in excess of 88 KV or 125 Kv.P.	2.0
Not in excess of 100 KV or 150 Kv.P.	2.5
Not in excess of 125 KV or 175 Kv.P.	3.0
Not in excess of 140 KV or 200 Kv.P.	4.0
Not in excess of 160 KV or 225 Kv.P.	5.0
Not in excess of 210 KV or 300 Kv.P.	9.0
Not in excess of 280 KV or 400 Kv.P.	15.0
Not in excess of 350 KV or 500 Kv.P.	22.0
Not in excess of 425 KV or 600 Kv.P.	34.0

The above tables in conjunction with the use of equation (122) will prove of great assistance in arriving at a solution of complete X-ray protection in matters of design and construction for an adequately equipped X-ray laboratory. The different materials included in Table XIV are suggestive of their adaptability to the particular type of building structure in the providing of an absolute ray-shielding.

3. High Tension Precaution and Safety Regulations In X-Ray Rooms.—The ever-existing hazard of accidental injury to the personnel as well as to the patient especially in laboratories equipped with older type X-ray apparatus makes the provision of safety devices and application of precautionary regulations highly desirable. Although in the case of a modern X-ray laboratory furnished with up-to-date X-ray installation this section of the writing would appear somewhat superfluous, nevertheless, in view of quite many laboratories in which older equipment with unprotected tube terminals, bare aerials, and associated conduit leads, comparatively less efficiently insulated control handles, panels, etc., the presentation of some of the essential precautionary procedures would not be considered as out of place.

The provision of a liberal distance from high-tension conductors in the X-ray room presents the best assurance of safety against electrical hazards. The latter can be further minimized by covering the floors with adequately insulating material, such as cork, wood, rubber, linoleum, fibre, or other synthetically produced insulators. This will insure to a large extent against hazards of accidental contact with high-voltage conductors.

To further eliminate the production of nitrous gases, ozone, etc., and the possibility of establishing a human contact with bare overhead conductors, the latter are made of coronaless brass tubings of large diameter and installed at least three meters (9 ft.) from the floor. The associated flexible conduits from aerials are kept taut by means of rheophores, as in case these leads do not make tight connections between the aerial and the X-ray tube, there is the possibility of the cathode leads short-circuiting the current supply to the filament of the tube. All exposed parts of the equipment should be grounded; and, in the case of an apparatus employing a shock-proof tube, the high-tension cables leading the current to the X-ray tube should be heavily insulated and their protective metal

sheathing efficiently grounded.

The use of sensitive double-pole circuit cut-outs and suitably indicated supply switches, and sockets fitted with fuses rated to carry only the normal maximum load of the given apparatus, is strongly recommended.

All condenser rectifier units should be provided with an automatic capacitor discharge relay. The purpose for the inclusion of this device is to avoid the presence of a residual charge after the unit is turned off. Furthermore, should the operator, for some reason, decide, after the capacitors are charged, to shut down the machine without making any exposure, the automatic relay immediately short-circuits the condensers to the ground, preventing a discharge through the X-ray tube.

Readily inflammable anaesthetics should be employed with great caution. Whenever possible, a non-inflammable anaesthetic substitute is preferable.

Due to ever-existing electrical hazards especially in the case of old apparatus the X-ray personnel should be trained to administer first-aid or artificial respiration to the victim of an accidental electric shock.

To preclude the disseminated radiations from adjacent rooms, the X-ray diagnostic room should be lined with sheet lead of 0.5 mm or with a material of equivalent screening power. Wherever tube rectifiers are employed in the rectification system they should be preferably installed in a separate compartment or shielded by lead-glass or any other material of 1.0 mm lead equivalent.

Again, if the discriminating radiologist restricts his equipment to modern apparatus manufactured by a reliable firm, he and his staff may go about their work without the slightest worry as regards the electrical and X-ray protection, and much annoyance is avoided. X-ray applications which with older forms of non-shock-proof, and non-ray-proof constructions were restricted to safe focal-object distances are now extended practically to an unlimited number of procedures. Compactness of construction, and built-in X-ray protection together with 100% electrical safety of the modern X-ray equipment have increased its flexibility of use with unrestricted movement, improving its efficiency of performance.

4. Sanitation In X-Ray Rooms.—All persons occupied in radiological work are quite familiar with the working conditions especially in an X-ray diagnostic room. Here, for the comfort of the patient who is most likely half-undressed for either fluoroscopic or radiographic diagnosis, the room is kept comparatively warm, and, for fluoroscopic work, it is also darkened. Accordingly, all windows and doors are shut tightly to exclude all light from the room. The diagnosis continues at least several minutes, and with laboratories doing considerable work of this type daily, the patients are consecutively attended without sufficient time and attention allowed to rejuvenate the air in the room. Consequently, the air is contaminated with nitrous fumes, ozone, carbon dioxide, and impure breath from those that have occupied the room. Such conditions are quite common with many laboratories where the undiscriminating personnel not only menace their own health but that of the patient as well. The practice should be regarded as mal-prophylaxis, and should further be strictly supervised by the city salutary measures. The author has had several occasions to meet members of the X-ray staff suffering from temporary systemic dis-

orders as a direct result of existing conditions in the X-ray rooms especially during winter months.

The American X-Ray and Protection Committee in co-operation with the International Congress of Radiology has adopted a series of safety recommendations and unified protective measures to improve the working conditions of X-ray practitioners. A copy of the pamphlet form may be secured from the Superintendent of Documents, Bureau of Standards, Washington, D. C. It is suggested that every X-ray operator should be familiar wih the content of the document, and that current revisions on safety recommendations published after each Congress should be preserved for reference.

Some of the essential conditions to be observed for the health and safety of the X-ray worker is to provide the X-ray department not lower than ground level. Adequate exhaust ventilation for all rooms, including the processing room, should be provided to remove all deleterious gases. Further facilities should be had for affording effective lighting and, where possible, for admitting sunshine and circulating fresh-air into the room, which must be of liberal dimensions. In case natural ventilation can not be obtained under the conditions prevailing, artificial circulation of the air should be supplied (at the rate of 25 to 40 cu. ft. per minute) by motor-driven fan units. A most modern method of providing adequate ventilation and humidity, and of maintaining a constant temperature (about 65°F.) of the X-ray room is an air-conditioning device obtainable from General Electric, Westinghouse, and many other electrical supply dealers.

The finish of all rooms should be of a pleasant tone and easily adaptable to the eyes. Lighter colors for the X-ray room, and "rose" or apple-green for the processing room, are preferable. Apppopriate paints for any color scheme with valuable suggestions for blending such colors to give a decorative effect with the need of the particular department may be obtained from any photographic supply dealer. Especially recommended for the processing room are the Kodacoat Paint[1] for finishing the lower walls, and the Kodak Panchromatic Green Paint[2] for upper walls. The former is an acid-and-alkali-resistant, non-inflammable, glossy black paint. In contrast with these, the ceilings may be painted white.

A high-voltage roentgen generating apparatus for therapy work should be placed in an adjoining room and the current led to the X-ray tube through heavily insulated flexible cables. The procedure minimizes all corona discharges, and thus aids in the effective promotion of health and safety conditions of the X-ray worker.

5. Medical Examinations For X-Ray Operators.—It has already been pointed out that susceptibility to cumulative effect of small X-ray doses is an impending condition and is dependent upon the loyal co-operation of the X-ray personnel. It is generally known that indiscriminate exposure to the radiation produces in the tissues injuries of chronic character. Of all the tissues of the human body, the blood cells and the organs forming them, germinal cells, and the epidermis exhibit distinct sensitivity to X-rays —blood cells being more than twice as sensitive as the epidermal cells. Leukopenia, anemia, cancerous ulcerations, and sterility as a result of

[1,2]Obtainable through Eastman Kodak Company.

X-ray injuries are quite generally known. Data on the subject is mostly procured by observations of the effect produced upon the early investigators unduly exposed to the radiation. Fatal consequences as a result of such exposures have also been reported.

Mention was also made that small daily doses are not harmful to the body, but these must be checked frequently so that the exposure will not exceed the permissible dose.

To arrive at an objective attitude as regards the permanent occupational injuries caused by X-rays, a quantitative investigation carried out for one year on three groups of persons engaged in X-ray and related work is reported by Burger[1]. The results show that with adequate protection only secondary rays were concerned in the investigation and that the average radiation received by each of the workers has amounted to not more than 0.01-r per square centimeter of the skin surface during each working day. No harmful effect has been observed at the end of the investigation period, as this quantity of radiation is far less than that permissible per day. Both qualitative and quantitative measurements of the daily radiation dose have been made by a convenient method indicated by Bouwers and van der Tuuk[2].

Since no practical method of efficacious elimination of the disseminated secondary rays has yet been brought to light, the X-ray personnel is constantly subject to the influence of the radiation. It is highly advisable, therefore, that periodic blood-corpuscle counts be made of these workers to remove symptoms of excessive exposure, if any, at an early stage. In many of the X-ray laboratories which have gained recognition of the medical profession, it has become a routine practice to examine the workers once a month or bimonthly for X-ray injuries. The working hours of the staff are, in some institutions, fixed to seven hours per day for not more than five days a week, with a month's vacation preferably during summer months.

If extensive protection against primary rays is provided (which is the case with modern equipment), it will be found that the tendency of an ill effect attendant to the health of the worker is not usually associated with the radiation but is indicative of inadequate ventilation and improper working conditions. Plenty of sunshine, fresh air, and physical exercise will generally remove the cause.

[1]G. C. E. Burger, M.D., of Philips Metalix Research Staff.

[2]Brit. J. Radiology, page 503, Vol. 3, 1940.

QUESTIONS ON CHAPTER XX

1. (a) What new developments have contributed to the solution of the problem of complete electrical and X-ray protection?

   (b) State some of the essential electrical measures to be considered in working in X-ray quarters.

2. (a) Of what significance is the grounding of the X-ray primary circuit?

   (b) What protective measures can be employed so that the hazard from accidental

contact with the X-ray secondary circuit may be minimized?

3. (a) Which is more preferable, grounding the transformer secondary at its center or insulating it entirely from ground? Why? Give your reasons.
   (b) How much protection do safety devices offer in preventing an accidental shock from high tension?
4. (a) What impetus in the manufacture of X-ray apparatus is given from the viewpoint of electrical safety?
   (b) What properties of X-rays make it necessary to preclude them from living cells?
5. (a) Which tissue cells exhibit the highest radiosensitivity? Is sterilization by X-rays subject to permanent degenerated conditions of the germ cells?
   (b) State the chief determinant as to whether the necrotic reaction as a result of undue exposure to X-rays will occur in the peripheral or in the deep-lying tissue structures.
6. (a) Give steps leading to the complete disintegration of a tissue structure by X-radiations.
   (b) What protective measures can be employed to screen off X-rays from the operator?
7. (a) On what consideration are the estimates for producing an erythema reaction based? What is an erythema dose? How much is the proposed tolerance dose per day?
   (b) Discuss the safe exposure limits to a single area of the human body. On what factors is the variability of exposure limits dependent?
   (c) Of what importance are Aluminum filters in radiography?
8. (a) What improvements in modern X-ray equipment render flexibility of use and unrestricted movement of the apparatus?
   (b) How are the lead-equivalent screening powers of different materials determined?
9. (a) Using Table XIV and equation (122), determine the thickness required of a wall of steel 120 cms from the X-ray target to reduce the X-radiation from the tube excited at 60 kilovolts to 1/120th of the original intensity.
   (b) Discuss the electrical precautions and safety regulations in X-ray rooms.
10. (a) Give some of the essential conditions to be observed in promoting hygienic atmosphere in X-ray rooms.
    (b) What conditions appear to be the chief causes menacing (if any) the health of the X-ray operator? Can these conditions be restricted? If so, how?

APPENDIX I

ELEMENTS AND THEIR CHARACTERISTICS

Element	Symbol	At. No.	At. Wt.	Valence	Melting Point °C.	Ionization Potential
Actinium	Ac	89	227.00	......	....	....
Alabamine	Ab	85	221.00	......	....	....
Aluminum	Al	13	26.97	3	660.0	5.96
Antimony	Sb	51	121.76	3, 5	630.5	8.5
Argon	A	18	39.94	0	− 189.2	15.69
Arsenic	As	33	74.93	3, 5	814.0	10.0
Barium	Ba	56	137.36	2	850.0	5.19
Beryllium	Be	4	9.02	2	1350.0	9.28
Bismuth	Bi	83	209.0	3, 5	271.0	8.0
Boron	B	5	10.82	3	2300.0	8.28
Bromine	Br	35	79.91	1	−7.2	11.8
Cadmium	Cd	48	112.41	2	320.9	8.96
Calcium	Ca	20	40.08	2	810.0	6.09
Carbon	C	6	12.00	2, 4	>3500.0	11.22
Cerium	Ce	58	140.13	4, 3	640.0	....
Cesium	Cs	55	132.81	1	26.4	3.87
Chlorine	Cl	17	35.45	1	−101.6	12.96
Chromium	Cr	24	52.01	2, 3, 6	1615.0	6.74
Cobalt	Co	27	58.94	2, 3	1480.0	8.5
Columbium	Cb	41	93.30	3, 5	1950.0	....
Copper	Cu	29	63.57	1, 2	1083.0	7.68
Dysprosium	Dy	66	162.46	3	....	....
Erbium	Er	68	167.64	3	....	....
Europium	Eu	63	152.00	3	....	....
Fluorine	F	9	19.0	1	−223.0	18.6
Gadolinium	Gd	64	157.30	3	....	....
Gallium	Ga	31	69.72	3	29.75	5.97
Germanium	Ge	32	72.60	4	958.5	8.09
Gold	Au	79	197.20	1, 3	1063.0	9.2
Hafnium	Hf	72	178.60	......	1700.?	....
Helium	He	2	4.00	0	<−272.2	24.46
Holmium	Ho	67	163.50	3	....	....
Hydrogen	H	1	1.0078	1	−259.1	13.53
Illinium	Il	61	146.00	......	....	....
Indium	In	49	114.80	3	155.0	....
Iodine	I	53	126.93	1	113.5	10.0
Iridium	Ir	77	193.10	3, 4	2350.0	....
Iron (cast)	Fe	26	55.84	2, 3	1275.0	7.83
Krypton	Kr	36	82.90	0	−169.0	13.94
Lanthanum	La	57	138.90	3	826.0	....
Lead	Pb	82	207.22	2, 4	327.5	7.38
Lithium	Li	3	6.94	1	186.0	5.37
Lutecium	Lu	71	175.00	3	....	....
Magnesium	Mg	12	24.32	2	651.0	7.61

Element	Symbol	At. No.	At. Wt.	Valence	Melting Point °C.	Ionization Potential
Manganese	Mn	25	54.93	2, 4, 6, 7	1260.0	7.41
Masurium	Ma	43	....	....	....	....
Mercury	Hg	80	200.61	1, 2	−38.87	10.38
Molybdenum	Mo	42	96.00	3, 4, 6	2620.0	7.35
Neodymium	Nd	60	144.27	3	840.0	....
Neon	Ne	10	20.18	0	−248.67	21.47
Nickel	Ni	28	58.69	2, 3	1452.0	7.61
Nitrogen	N	7	14.008	3, 5	−209.86	14.48
Osmium	Os	76	190.80	2, 3, 4, 8	2700.00	....
Oxygen	O	8	16.00	2	−218.4	13.55
Palladium	Pd	46	106.70	2, 4	1555.0	8.3
Phosphorus	P	15	31.02	3, 5	44.1	....
Platinum	Pt	78	195.23	2, 4	1755.0	8.9
Polonium	Po	84	210.00	....	....	....
Potassium	K	19	39.10	1	62.3	4.32
Proseodymium	Pr	59	140.92	3	940.0	....
Protactinium	Pa	91	....	....	....	....
Radium	Ra	88	225.97	2	960.0	10.2
Radon	Rn	86	222.00	0	....	10.69
Rhenium	Re	75	186.31	....	3000.?	....
Rhodium	Rh	45	102.91	3	1955.0	7.7
Rubidium	Rb	37	85.44	1	38.5	4.16
Ruthenium	Ru	44	101.70	3, 4, 6, 8	....	....
Samarium	Sm	62	150.43	3	>1300.0	....
Scandium	Sc	21	45.10	3	1200.0	6.7
Selenium	Se	34	79.20	2, 4, 6	220.0	9.5
Silicon	Si	14	28.06	4	....	8.12
Silver	Ag	47	107.88	1	960.5	7.54
Sodium	Na	11	22.997	1	97.5	5.12
Strontium	Sr	38	87.63	2	800.0	5.67
Sulphur	S	16	32.06	2, 4, 6	120.0	10.3
Tantalum	Ta	73	181.40	5	2850.0	....
Tellurium	Te	52	127.50	2, 4, 6	452.0	....
Terbium	Tb	65	159.20	3	....	....
Thallium	Tl	81	204.39	1, 3	303.5	6.07
Thorium	Th	90	232.12	4	1845.0	....
Thulium	Tm	69	169.40	3	....	....
Tin	Sn	50	118.70	2, 4	170.0	7.30
Titanium	Ti	22	47.90	3, 4	1800.0	6.81
Tungsten	W	74	184.00	6	3370.0	....
Uranium	U	92	238.14	2, 4, 6	< 1850.0	....
Vanadium	V	23	50.95	3, 5	1710.0	6.76
Virginium	Vi	87	224.00	....	....	....
Xenon	Xe	54	131.30	0	−140.0	12.08
Ytterbium	Yb	70	173.50	3	....	....
Yttrium	Y	39	88.92	3	1490.0	6.5
Zinc	Zn	30	65.38	2, 4	419.4	9.36
Zirconium	Zr	40	91.22	4	1700.0	6.92

APPENDIX II

ELECTROMAGNETIC RADIATIONS

Type	Wave-Length In A.U.	Frequency (approx.) Cycles/Second
Cosmic Rays	.00005 – ?	3.7×10^{22}
Gamma Rays	0.01 – 1.4 0.05 – 0.5 used in radiography.	$3 \times 10^{20} - 2.14 \times 10^{18}$
X-Rays	0.05 – 1100 0.05 – 0.5 used in radiography	$5 \times 10^{19} - 2.72 \times 10^{15}$
Ultra-Violet Rays.	136 – 3900	$2.3 \times 10^{16} - 7.7 \times 10^{14}$
Visible Rays Violet Blue Green Yellow Orange Red	3900 – 8000 3900 – 4220 4220 – 4920 4920 – 5350 5350 – 5860 5860 – 6470 6470 – 8000	$7.7 \times 10^{14} - 4.7 \times 10^{14}$
Infra-Red Rays	$8000 - 4.2 \times 10^{6}$	$4.7 \times 10^{14} - 7.7 \times 10^{11}$
Hertzian Waves (short)	$10^{6} - 10^{11}$	$3 \times 10^{12} - 3 \times 10^{7}$
Radio Waves	$10^{11} - 3 \times 10^{14}$	$3 \times 10^{7} - 10^{4}$
Electric Waves	$3 \times 10^{14} - 1.2 \times 10^{17}$	$10^{4} - 25$

APPENDIX III

IMPORTANT PHYSICAL CONSTANTS

Electrical Units:—		
Charge (quantity):—		
Electronic Charge (e) . .	=	4.77×10^{-10} e.s.u.
	=	1.592×10^{-20} e.m.u.
	=	1.592×10^{-19} coulomb.
Coulomb (Q)	=	10^{-1} e.m.u.
	=	3×10^{9} e.s.u.
	=	6.28×10^{18} electronic charges.
Microcoulomb (μQ) . .	=	10^{-6} coulomb.
Faraday	=	96,500 coulombs.
Current:—		
Ampere (I)	=	10^{-1} e.m.u.
	=	3×10^{9} e.s.u.
	=	1 coulomb per second.
	=	1.036×10^{-5} faraday per second.
Milliampere (MA) . . .	=	10^{-3} ampere.
Micro-ampere (μA) . .	=	10^{-6} ampere.
Potential:—		
Volt (E or V)	=	10^{8} e.m.u.
	=	10^{8} gausses.
	=	$1/3 \times 10^{-2}$ e.s.u.
Kilovolt (KV)	=	1000 volts.
Million-Volt (MV) . . .	=	10^{6} volts.
Millivolt	=	10^{-3} volt.
Microvolt	=	10^{-6} volt.
Resistance:—		
Ohm (R or r)	=	The resistance of a uniform column of mercury 106.3 cms long, at 0°C, having a mass of 14.452 grams.
	=	10^{9} e.m.u.
	=	$1/9 \times 10^{-11}$ e.s.u.
Megohm	=	10^{6} ohms.
Microhm	=	10^{-6} ohm.
	=	10^{-12} megohm.
Capacity:—		
Farad (C)	=	10^{-9} e.m.u.
	=	9×10^{11} e.s.u.
	=	10^{6} microfarads.
Microfarad (μC)	=	10^{-6} farad.
Micro-microfarad ($\mu\mu C$)	=	10^{-12} farad.

Inductance:—

Henry (L)	$= 10^9$ e.m.u.
	$= 1/9 \times 10^{-11}$ e.s.u.
Millihenry	$= 10^{-3}$ henry.

Magnetic Units:—

1 line of force = 1 maxwell = 1 e.m.u. = 10^{-8} volt-second.
1 gauss = 1 maxwell/sq. cm. = 1 line/sq. cm.
1 gilbert = 1 gauss-centimeter.
Magneton (Bohr) = 9.22×10^{-21} erg per gauss.

Other Constants:—

$$\text{Velocity of Light} = \frac{\text{Electrostatic Unit}}{\text{Electromagnetic Unit}}$$

$$= \frac{\text{e.s.u.}}{\text{e.m.u.}} = 3 \times 10^{10} \text{ cms/second.}$$

Positron Charge (positive electron) = 4.77×10^{-10} e.s.u.
Positron Mass = 9.038×10^{-28} gram.
Electron Mass = 9.038×10^{-28} gram.
Mass of Proton = 1.66×10^{-24} gram.
e/m = 5.2741×10^{17} e.s.u. per gram.

Electron-volt = 1.59×10^{-12} erg.
1 erg $\doteq 0.629 \times 10^{12}$ electron-volts.

Gas Constant (R)	= 1.9864 calories/degree/mole.
	= 8.3136×10^7 ergs/degree/mole.
Avogadro's Number	= 6.06×10^{23} per mole.
Planck's Constant	= 6.55×10^{-27} erg-second.
Boltzmann's Constant	= 1.3708×10^{-16} erg/degree.

Grating Space of Rock Salt ($NaCl$)	= 2.8 A.U. (approx.)
Grating Space of Calcite ($CaCO_3$)	= 3.0 A.U. (approx.)
Grating Space of Mica	= 9.9 A.U. (approx.)
Grating Space of Quartz (SiO_2)	= 4.2 A.U. (approx.)

Gravitational Constant (G) = 6.66×10^{-8} C.G.S. Units.
Radius of Earth (Equatorial) = 6.3784×10^8 cms.
Mean Density of Earth = 5.52 grams per Cc.
Mean Distance From Earth To Sun = 1.495×10^{13} cms.
Mean Distance From Earth To Moon = 3.844×10^{10} cms.

APPENDIX IV

INTERNATIONAL WEIGHTS AND MEASUREMENTS

— Units of Length —

Angstrom Units	Microns	Milli-meters	Centi-meters	Inches	Meters
1	10^{-4}	10^{-7}	10^{-8}	2.5×10^{-8}	10^{-10}
10^4	1	10^{-3}	10^{-4}	2.5×10^{-4}	10^{-6}
10^7	10^3	1	1/10	1/25	10^{-3}
10^8	10^4	10	1	2/5	10^{-2}
2.54×10^8	2.54×10^4	25.4	2.54	1	1/39
10^{10}	10^6	10^3	10^2	39.4	1

1 light year = 5.9×10^{12} miles = 9.5×10^{12} kilometers.
1 kilometer = 10^3 meters = 10^5 cms. = 10^6 millimeters.
1 mile = 1760 yards = 5280 feet = 63,360 inches.
1 yard = 3 feet = 36 inches = .9144 meter
1 foot = 12 inches = .3048 meter
1 inch = 2.54 centimeters
1 meter = 1.093 yards = 3.279 feet = 39.37 inches.

— Units of Area —

1 square meter = 100 sq. decimeters = 10^4 sq. cms. = 10^6 sq. mms.
1 square mile = 640 acres = 3,097,600 sq. yds. = 27,878,400 sq. ft.
1 acre = 4840 sq. yds. = 43,560 sq. ft.
1 sq. yd. = 9 sq. ft.
1 sq. ft. = 144 sq. inches.

— Units of Volume —

1 cubic meter = 10^3 cubic decimeters = 10^6 cu. cms. = 10^9 cu. mms.
1 cubic decimeter = 10^3 cu. cms. = 10^6 cu. mms.
1 Cc = 10^3 cu. mms.
The weight of 1 Cc of water at 4° C. is 1 gram.

— Units of Capacity and Equivalents —

1 liter = 1000 Cc = 1000 milliliters
1 Cc = 1 milliliter = 16.2 minims (drops)
1 Cc distilled water = 1 milliliter distilled water = 1 gram

1 Gallon = 4 quarts = 8 pints = 128 fl. oz.
1 quart = 2 pints = 32 fl. oz.
1 pint = 16 fl. oz.
1 fl. oz. = 8 fl. drams = 29.57 mils = 29.57 Cc
1 fl. dram = 3.696 mils = 3.696 Cc

— Avoirdupois —

1 ton = 2000 pounds = 32000 ounces = 907.2 Kilograms
1 pound = 16 ounces = 453.59 grams
1 ounce = 28.34 grams
1 gram = 100 centigrams = 1000 milligrams = 15.43 grains
1 grain = .0648 gram = 6.48 centigram = 64.8 milligrams

— Units of Angle —

1 circumference = 360 degrees = 2π radians = ($2\pi r$; r = radius)
½ circumference = 180 degrees = π radians ($\pi = 3.1416$)

¼ circumference = 90 degrees = $\frac{\pi}{2}$ radians

⅛ circumference = 45 degrees = $\frac{\pi}{4}$ radians

1 degree = 60 minutes = 3600 seconds = 0.01745 radian
1 minute = 60 seconds
1 radian = 57° 17′ 44.8″ = 57.2958° (degrees)
1 knot (nautical mile) = length of 1′ (minute) of arc on Earth's equatorial surface.

APPENDIX V

STANDARD POSITIONING TECHNICS

Successful detection and interpretation of pathological conditions as indicated in a radiograph is largely dependent upon the technic employed for the exposure under consideration. The procedure can be standardized to assure regularity in the composition of detail delineation and thereby to augment the diagnostic value of the radiographic examination. In situations where the necessity for further study of the part under examination calls for a supplementary view at right angles to the first, or two views at slightly different positions of the tube target (stereoradiographs), normal relationship of the various structures fully orientated to disclose gross conditions becomes of undisputed value.

Radiography of anatomical structures is made possible owing to the presentations of differences in densities of various contiguous tissues constituting the human body. Bony structures, due to their Calcium content, are relatively impervious to X-rays, compared to soft tissue structures. The differences between the densities of skeletal and muscular, or visceral, tissue structures are what enable the visualization of the part for adequate diagnostic interpretation. The success of the latter is dependent upon the quality and the interpretable features of the radiograph. Without proper definition in the gradations of different tissue densities and the correct alignment of these structures relative to the incident radiation beam the diagnosis of the image will be rendered difficult. Proper positioning, indeed, is one of the chief determinants contributing to the making of an interpretable radiograph.

All obstructive materials must be excluded from the field of exposure to secure the maximum diagnostic value of the image. Wherever possible, all clothing, silk underwear, bandages, adhesive tapes, plaster casts, splints, medicated gauze, etc., should be removed from the part under examination. Gas or fecal matter in the intestinal tract prevent the visualization of the over- or under-lying structures, and hence the importance of complete evacuation of the colon precedent to radiographing the lumbar or sacral vertebrae, pelvic region, or visceral organs in the abdominal cavity.

In the radiological exploration of the gall bladder or the colon, injection of a radio-opaque substance is necessary in order to be able to discriminate these from other contiguous structures. For the former (colecystography) Cholemulsion, Shadokol, or Cholepulvis, whose base is tetraiodophenolphthalein, is administered intra-orally, whereas an emulsion of Barium Sulphate in fine suspension is injected into the colon through the rectum. For the examination of the kidneys, Ariodol emulsion (consisting of an iodized and chlorinated peanut oil containing 27% of Iodine and 7.5% of Chlorine in chemical combination with esters of fatty acids) is introduced into the kidney by way of the ureter catheterized. In radiography of the sinus tracts, urinary bladder, urethra, ureters, and cervix, the use of Thorad is recommended due to its property of clinging to mucosal sur-

faces and coagulating there in the presence of mucus or dilute alkalies.

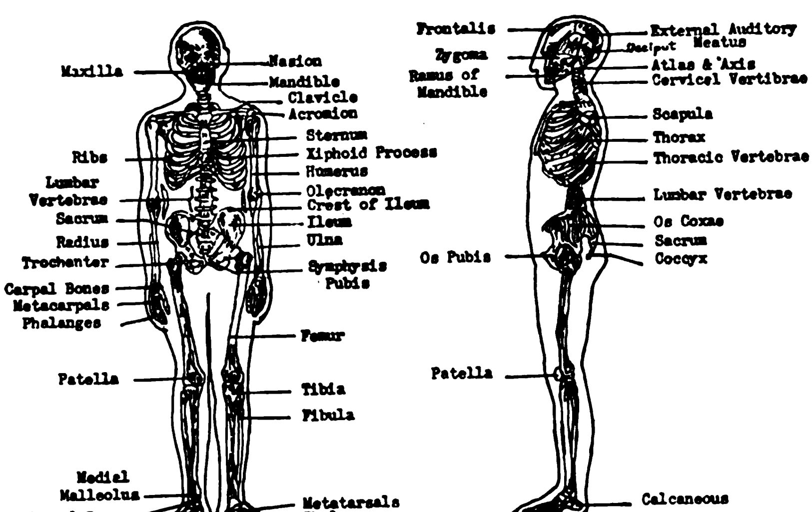
Positioning of a part for radiographing is accomplished by the alignment of a certain skeletal region, or regions, known as *"landmark"*, to the film with the principal ray directed to the center of the exposure field. These "landmarks" render it possible to ascertain the approximate location of a given visceral organ, extremity, appendage, or any other body structure.

Before an attempt is made, therefore, to describe various positioning technics in the accompanying sections, a survey of skeletal system designating the different parts, aspects, surfaces, and regions will aid in describing and locating the various anatomical structures of radiographic interest. The importance of the study is further augmented in view of the dependence of almost all soft parts upon the bony frame-work for attachment and support.

1. The Anatomy Of Skeletal System.—The bones form the skeleton of the human body, preserving its shape and affording shelter to delicate structures within its framework. They also constitute the principal organs of support and afford attachment to muscles, aiding the process of locomotion.

The skeletal bones considered in this text will be taken up in the following divisions: *The skull, trunk, bones of the upper extremity,* and the *bones of the lower extremity.* (See Fig. 182a and b.)

(*a*) *The Skull*:—The skull houses the most delicate and elaborate organ of the body, the brain. It is supported upon the spinal column, and consists of the cranial and facial bones. The structure further comprises cavities, sinuses, fossae, sutures, and processes.



(A) FRONT VIEW. (B) SIDE VIEW.

FIG. 182. THE SKELETON OF HUMAN BODY.

The bones of the skull may be classified into two divisions—cranial, and facial.

Cranium or Cranial Bones:—

Occipital—at the base of the skull.

Parietals—right and left, form the sides and roof of the skull.

Frontal—forms the forehead.

Temporals—right and left, situated above and back of ear region. It contains the zygomatic arch, auditory meatus, and the mastoid process.

Ethmoid—Situated back of nasal cavities.

Sphenoid—a wing-shaped structure, situated anteriorly to the base of the skull and back of orbit.

Facial Bones:—

Nasals—two in number, forming the frame of the nose.

Zygomatic (*malar*)—one on each side of face, and form the prominence of the cheeks.

Maxilla—right and left, form the upper jaw.

Mandible—lower jaw bone, known also as inferior maxillary bone. The nasal cavity is communicated with four sinuses which frequently become the seat of infection. They are—

Frontal sinuses—one on either side in the frontal region. They are filled with air and communicate with nasal cavity.

Ethmoid sinuses—lateral labyrinths, on either side of ethmoid bone, are thin-walled cavities and open into the nasal passages.

Sphenoidal sinuses—cavities in the back of the sphenoid bone. Posteriorly to roof of these cavities is the Sella Turcica lodging hypophysis.

Maxillary sinus (*Antrum of Highmore*)—large cavity in the body of each maxilla. It communicates with the nasal passages on their lateral walls.

Mastoid cells—Cancellous air-spaces in the mastoid bone situated posterior to auditory meatus.

The study of sinuses becomes important in view of the detection of their anomalities by radiographic methods. Since the mucous membrane of the nasal passages is continuous with these sinuses, the inflammatory conditions involving the former may extend into the sinuses, causing sinusitis, the examination of which is facilitated by means of X-rays.

(*b*) *The Trunk*:—The trunk consists of the *spinal vertebrae,* the *ribs,* and the *sternum.*

(1) The Spinal Vertebrae.—These are series of bones that constitute the vertebral column and the chief part of the axial skeleton. There are thirty-three vertebrae in the column, and they are distinguished according to what region they occupy in the vertebral column. The vertebrae are rceognized as—

Cervical—there are 7 in the cervical region.

Thoracic—there are 12 in the thoracic region.

Lumbar—there are 5 in the loin region.

Sacral—there are 5 in the pelvic region.

Coccygeal—there are 4 or 5 in the pelvic region.

The first and the second cervical vertebrae are known as the *Atlas,* and *Axis,* respectively. Arising from the upper anterior portion of the axis is a bony projection, known as the odontoid process, around which the atlas

rotates. These structures present particular importance in the radiographic diagnosis of the cervical region and the base of the skull.

The thoracic (dorsal) vertebrae are larger and their transverse processes are longer than those of the cervical vertebrae. The spinous processes of the first and 12th dorsal vertebrae are more prominent than the rest of the vertebrae of that division. Hence these two points are of interest and aid in the locating of different visceral structures in medical diagnosis.

The largest and heaviest of the spinal vertebrae are in the lumbar region. The fifth lumbar vertebra is of particular interest when searching for malignancy of that region. Since this vertebra forms articulation with the sacrum and is nearest the sacral plexus of the parasympathetic nervous system, the radiographic examination is often centered around this particular bone structure.

The sacrum is a large triangular bone (in the adult, it is formed by the fusion of 5 sacral vertebrae) forming a supporting bridge between the two hip bones on each side.

Four coccygeal segments (sometimes five) enter into the formation of the inferior terminal portion of the spinal column. These are comparatively very small, and are of rudimentary form.

(2) The Thorax.—The bony cage-like structure occupying the anterior aspect of the twelve thoracic vertebrae is called the thorax. It is composed of twelve ribs on each side, articulating with the sternum in front, and posteriorly with the bodies of the thoracic vertebrae.

The thoracic cavity contains some of the vital organs, such as the *Heart, Lungs,* and other important structures.

(*c*) *The Extremities*:—Aside from axial skeleton, there is an appendicular skeleton which includes the bones of the upper and lower extremities.

The upper extremity comprises the shoulder-girdle, which consists of two collar bones (*clavicles*) and two shoulder blades (*scapulae*); and, one on each side, a *humerus* (armbone), *ulna* (elbow bone), *radius*, 8 *carpal* (wrist) *bones*, 5 *metacarpals*, and 14 *phalanges* (2 in thumb, and 3 in each of the other fingers.)

At the shoulder joint, the scapula articulates, by means of its glenoid cavity, with the humerus, and through the acromion process with the clavicle. The humerus, in turn, articulates at its lower extremity with the ulna and radius. The rest of the bones articulate successively with each other in the order of sequence given above.

Corresponding in general with the bones of the upper extremity, the structure of the lower extremity contains the two hip bones (developed by the union of *ileum, ischium*, and *os pubis*), and on either side a thigh bone (*femur*), knee-cap (*patella*), shin-bone (*tibia*), calf-bone (*fibula*), 7 tarsal (*tarsus*) bones, 5 *metatarsal bones*, and 14 *phalanges*, which resemble these in the hand in general arrangement.

The hip bones (*os coxae*) on either side form the pelvic girdle by the union with the sacrum behind. The head of the femur articulates with the *acetabulum* (cavity) of os coxa, and its lower end articulates with the tibia and the patella. The tibia also articulates with both the upper and lower ends of the fibula. Both of these bones further articulate with the

talus of the tarsal bones. The remainder of the bones articulate with each other in the order given above.

(*d*) *Anatomical Landmarks*:—In radiography, routine positioning technic requires the correct alignment of the part being examined in respect with the radiation source and the recording surface. In order to be able to locate the body structures imperceptible externally, and to restrict the field of exposure to a definite area, anatomical landmarks consisting of definite parts or regions of certain bones serve to centralize the area under consideration to the film. These *landmarks* vary in character from a *surface, prominence, tuberosity, symphysis, ridge, crest,* or *process,* to the *body of the bone* as a whole. A thorough knowledge of these landmarks, therefore, become of particular importance in the roentgenographic considerations of various anatomical structures.

The anatomical landmarks of each part whose routine positioning technic is considered in this text will be presented under the appropriate heading included in the section on standard positions.

2. Standard Positions.—The positioning procedures in subsequence are only those met in routine diagnostic radiography. Other technics not given here can be formed by the practitioner after he has once mastered the relatively simple but important fundamentals presented below.

For special convenience, all radiographic exposure factors have been reduced to a few basic forms in Table XVI, from which pertinent technics may be obtained by use of some prudence and knowledge already acquired from preceding studies. To use the table, instructions given under *"radiographic technic"* of the particular part to be radiographed should be closely followed.

To further elucidate the use of this chart, let us assume that it is desired to make a radiograph of the lateral view of the cervical spine. The kilovoltage to be used is first determined by measuring the thickness of the part; and, let us further assume that this thickness is 12 cms. The proper Kv.P. can then be computed by use of the equation

$$\begin{aligned} Kv.P. &= (Cms. \times 2) + 30 \\ &= (12 \times 2) + 30 = 54 \qquad Ans. \end{aligned}$$

If no Bucky diaphragm is to be employed in the technic, the millamperage, time, and the distance factors are determined by consulting the chart under "Cervical Spine", which, for the lateral view of this region, gives

100 MA., 0.6 second, 72 inches.

The radiographic technic then will be

54 *Kv.P.*, 100 MA., 0.6 second, and 72 inches.

If cardboard technic is desired, the thickness of the part is determined as usual, and the corresponding Kv.P. is obtained by referring to the Kv.P. column across appropriate Milliampere-Second factor chosen. For example, the cardboard technic for the cervical spine of thickness 12 cms., using, for instance, 66 MA-S, and non-screen films, will be

60 *Kv.P.*, 20 MA., 3.3 seconds, 30 inches.

Table XVI: Chart Giving Exposure Factors For Different Parts.

Anatomical Part	Projection	Focal-Film Distance	Exposure Time In Seconds			
			Screens		Screens & Bucky	
			20-MA	100-MA	20-MA	100-MA
Extremities	AP, PA	36″	0.6	0.15	2.0	0.4
	LAT, OBL	36″	0.7	0.20	2.1	0.45
Pelvis	AP	30″	6.0	1.20	15.0	
The Trunk:—						
Lumbar Spine	AP, LAT	30″	1.3		7.5	
Sacral Spine	AP, LAT	30″	1.3		7.5	
Dorsal Spine	AP, LAT	30″	0.6		1.5	
Dorsal Spine	LAT, (VERT.)	72″	2.8	0.60		
Cervical Spine	AP	30″	0.8	0.20	2.0	0.6
Cervical Spine	LAT	72″	2.8	0.60		
Chest (Vert.)	AP, PA	72″	0.25	0.05	0.8	0.16
Chest (Vert.)	LAT	72″		0.15		
Sternum	PA	30″	0.55	0.05	1.7	0.68
The Skull:—						
Head	PA, AP	30″	1.0	0.20	3.0	0.7
Head	LAT	30″	0.8	0.15	2.0	0.5
Jaw	LAT	30″	0.8	0.15	2.0	0.4
Mastoid	LAT	30″	4.0	0.80	8.8	1.75
Nasal Sinuses	Special Angulation		3.0	0.60	7.5	1.50
The Organs:—						
Heart (prone)	PA, AP	42″	0.20		0.7	
Heart	LAT, OBL	42″	0.35		1.0	
Lungs (prone)	PA, AP	42″	0.20		0.7	
Lungs	LAT, OBL	42″	0.35		1.0	
Stomach	PA, AP, OBL	30″	0.10			1.0
Gastro-Intestinal Tract.	AP, PA	30″	4.50	0.90	3.0	0.6
Gall Bladder	PA	30″	0.60	0.15	1.6	0.36
Kidneys	AP	30″	4.50	0.90	3.0	0.6
Pelvimetry	AP, LAT	30″	2.20	0.45	7.0	1.4

Cardboard Technic – 9″ Cone – Field At 30″.

Film:—	Cms.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	At
Non-Screen-*Kv.P.*		30	32	35	37	40	43	45	48	51	53	57	60	62	65	68	70	73	66 Ma-S.
Regular-*Kv.P.*		38	41	44	47	51	54	57	60	63	65	67	70	73	75	78	81	84	100 MA-S.

Kv.P. = (Cms. × 2) + *X**

*The value of "*X*" is given under each radiographic technic.

A. Upper Extremities:—

(1) *Part — Hand.*

(a) Projection — PA (Palmar)
Landmark — The knuckles.
Film — 4 x 5, or 8 x 10.
Position — Place hand on the exposure holder, with palm surface down, and the line of knuckles at the center of the exposure field. Immobilize hand by placing a sand bag on middle of forearm.
Tube — Direct principal ray perpendicularly to the line of knuckles.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(b) Projection — Oblique.
Landmark — Midportion of dorsum of hand.
Film — 4 x 5, or 8 x 10.
Position — Have the patient's hand rest obliquely on the film, with the tips of the fingers spread out and slightly flexed. Immobilize with sand bag over forearm.
Tube — Direct principal ray to the center of the exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(2) *Part — Wrist*

(a) Projection — PA.
Landmark — Midjoint of wrist joint.
Film — 4 x 5, or 8 x 10.
Position — Place wrist on the center of the film holder, with palmar surface down, and immobilize with sand bag on the forearm.
Tube — Direct principal ray perpendicularly to the center of the exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(b) Projection — Medial.
Landmark — ½ inch proximal to styloid process of radius.
Film — 4 x 5, or 8 x 10.
Position — Place ulnar side of the wrist on exposure holder, hand extended, thumb pointing forward. Immobilize with sand bag across forearm.
Tube — Center principal ray perpendicularly to area of exposure.
Radiographic Technic — Measure thickness of part. Consult

chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(3) *Part — Elbow.*

(a) Projection — AP.
Landmark — Olecranon process of ulna.
Film — 8 x 10 lengthwise with arm.
Position — Extend forearm fully in a supine position, and place olecranon process on the center of the film. Immobilize by placing sand bag on lower third of forearm, and on middle of humerus.
Tube — Direct principal ray perpendicularly to the center of exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(b) Projection — Lateral or medial.
Landmark — Medial condyle of humerus.
Film — 8 x 10. (AP & LAT on one film preferred.)
Position — Rest arm and forearm on exposure holder, with medial condyle of the humerus and styloid process of ulna near film. Raise thumb, with elbow slightly flexed. Immobilize with sand bags on lower third of forearm and middle of humerus.
Tube — Direct principal ray to head of radius in center of exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30.

(4) *Part — Shoulder.*

(a) Projection — AP.
Landmark — Head of humerus.
Film — 8 x 10. Use Bucky diaphragm if necessary.
Position — Patient lying on back with arms close to his side, place shoulder on center of exposure holder and direct principal ray through coracoid process of scapula. Have patient suspend respiration during exposure.
Tube — Center tube to the exposure area.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(b) Projection — PA.
Landmark — Mid-region of clavicle.
Film — 8 x 10.
Position — Patient lies prone with arms close to his side, and face turned in opposite direction from exposed shoulder. Center mid-region of clavicle to film. Have patient stop breathing during exposure.
Tube — Principal ray directed to center of exposure area.
Radiographic Technic — Measure thickness of part. Consult

chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(5) *Part — Scapula.*
Projection — PA.
Landmark — Acromion process.
Film — 8 x 10.
Position — Have patient stand with breast against the vertically-mounted cassette, and have him raise his arm on the affected side above his head. Center region two inches below the midpoint of clavicle to film. Have patient stop breathing during exposure.
Tube—Direct principal ray perpendicularly to the center of the exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

B. Lower Extremities:—

(1) *Part — Foot.*
(a) Projection — Plantar.
Landmark — Mid-portion of foot.
Film — 8 x 10.
Position — Patient lying on his back, with knee on affected side flexed, and plantar surface of foot placed on the exposure holder. Center mid-portion of foot to the film. Immobilize foot with compression band, if necessary.
Tube — Rotate tube 10° toward head. Direct principal ray to the center of exposure area.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30
(b) Projection — Lateral.
Landmark — Proximal end of the middle metatarsal bone.
Film — 8 x 10.
Position — Patient lying on affected side with lateral side of foot resting on the cassette. Center mid-tarsal region to film, and immobilize with sand bags over leg.
Tube — Direct principal ray to center of exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(2) *Part — Ankle.*
(a) Projection — AP.
Landmark —Mid-portion of ankle joint (between medial and lateral malleoli).
Film — 8 x 10.
Position — The patient either sits or lies on back with his heel resting on exposure holder and toes pointing normally forward. Center mid-portion of ankle joint to film. Immobilize part with sand bag on fore-leg.

Tube — Direct principal ray to center of exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for the use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(b) Projection — Lateral.
Landmark — Depression below medial malleolus of tibia.
Film — 8 x 10.
Position — Patient lying on side, place lateral side of ankle on exposure holder. Center depression below malleolus to film. Immobilize with sand bag over leg.
Tube — Direct principal ray perpendicularly to center of area of exposure.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(c) Projection — Oblique.
Film — 8 x 10.
Position — Patient sitting on table, knee flexed, place plantar surface of foot on exposure holder. Shift medial malleolus to center of film. Immobilize patient if necessary.
Tube — Tilt tube 20 degrees toward medial aspect of foot. Direct principal ray to center of exposure area.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(3) *Part — Os Calcis.*
Projection — Special position (PA).
Landmark — Region between external and internal malleoli.
Film — 8 x 10.
Position — Patient lies in prone position, foot acutely flexed, and toes resting on table. Place the exposure holder in close contact with plantar surface of foot. Shift part to center of film, and immobilize with sand bags.
Tube — Rotate tube 45 degrees toward foot, and direct principal ray to two inches from palmar surface of os calcis.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(4) *Part —Patella*

(a) Projection — PA.
Landmark — Patella.
Film — 8 x 10. Use 5″ cone.
Position — Patient prone on table, shift patella to center of film. Immobilize with sand bag over fore-leg.
Tube — Direct principal ray perpendicularly to the center of the exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(b) Projection — Lateral.
Landmark — Patella.
Film — 8 x 10. Use 5″ cone.
Position — Patient lying in lateral position on affected side, knee slightly flexed, with patella on center of film. Immobilize fore-leg with sand bag.
Tube — Direct principal ray perpendicularly to mid-portion of the joint.
Radiographic Technic — Measure thickness of part. Consult chart for use of extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(5) *Part — Knee*

(a) Projection — AP, and PA.
Landmark — Lower margin of patella.
Film — 8 x 10. Use 5″ cone.
AP-Position — Patient lying on back, place knee on exposure holder and shift lower part of patella to center of film. Immobilize with sand bag over fore-leg.
PA-Position — Patient in prone position. Place patella to center of film. Immobilize with sand bag over fore-leg.
Tube — Direct principal ray perpendicularly to the center of field.
Radiographic Technic — Measure thickness of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

(b) Projection — Lateral
Landmark — Lower margin of patella.
Film — 8 x 10. Use 5″ cone.
Position — Patient lying on side, place lateral aspect of knee on exposure holder, knee slightly flexed. Immobilize with sand bags above and below knee.
Tube — Direct principal ray perpendicularly to lower portion of patella.
Radiographic Technic — Measure thicknes of part. Consult chart for extremities, or for use of cardboard technic.
Kv.P. = (Cms. x 2) + 30

High-Definition Technic:—See Figure 157.

Thickness — 12 Cms.
Distance — 30″
Grid Ratio — 8-1.
Focal Spot — 1.5 mm.

Film — Eastman Ultra-Speed.
Screens — Eastman High-Definition
Kv.P. = 85; MA-S = 10.

(6) *Part — Hip.*

(a) Projection — Posterior (AP).
Landmark — Greater trochanter of femur.
Film — 11 x 14, mounted in Potter-Bucky diaphragm.
Position — Patient lying on back, shift affected hip on film in correct alignment with X-ray tube. Mid-portion of inguinal ligament is centered to the film. Immobilize with sand bags over both fore-legs.

Tube — Direct principal ray to proper part.
Radiographic Technic — Measure thickness of part. Consult chart for extremities.
Kv.P. = (Cms. x 2) + 32

(b) Projection — Semi-Lateral (Oblique).
Landmark — Greater trochanter of femur.
Film — 8 x 10, with 5″ cone. Or, 11 x 14, and Bucky Diaphragm.
Position — Patient lying on side, the affected hip slightly flexed. The other leg raised and placed in a position off the field. Immobilize affected leg with sand bag.
Tube — Direct principal ray perpendicularly to femur.
Radiographic Technic — Measure Thickness of part. Consult chart for extremities.
Kv.P. = (Cms. x 2) + 32

(7) *Part — Coccyx.*

(a) Projection — Lateral.
Landmark — Iliac crest.
Film — 11 x 14. Use Potter-Bucky diaphragm.
Position — Patient lying on side in true lateral position, knees flexed, the crest of ileum is placed on the center of film, with body (of ileum) centered to diaphragm. Immobilize with compression band over the hips, and by having the patient breathe lightly during exposure.
Tube — Direct principal ray perpendicularly to 5th lumbar vertebra, or tilt tube, if necessary, to conform with lateral spinal curve.
Radiographic Technic — Measure thickness of part. Consult chart for sacral spine.
Kv.P. = (Cms. x 2) + 32

(b) Projection — Posterior (AP).
Landmark — Iliac crests and symphysis pubis.
Film — 14 x 17. Use Potter-Bucky diaphragm.
Position — Same as for pelvis.
Radiographic Technic — Same as for pelvis.

(8) *Part — Pelvis.*

Projection — Posterior (AP).
Landmark — Iliac crests and symphysis pubis.
Film — 14 x 17. Use Potter-Bucky diaphragm.
Position — Patient lying perfectly straight on back with iliac crests four inches from the top of the film placed lengthwise with body. Turn the toes inward, and immobilize part with compression band. Have the patient breathe lightly during exposure.
Tube — Direct principal ray perpendicularly to the center of the film and between umbilicus and symphysis pubis.
Radiographic Technic — Measure thickness of part. Consult chart for pelvis.
Kv.P. = (Cms x 2) + 30.

C. The Trunk:—

(1) *Part — Lumbar Spine.*

(a) Projection — Lateral.
Landmark — Iliac crests.
Film — 14 x 17. Use Potter-Bucky diaphragm.
Position — Patient lies on his side on the table in a true lateral position, the spine slightly to one side of the center line. Shift iliac crests to 1 or 2 inches below the center of the cassette. Knees slightly flexed.

If a detailed view of 5th lumbar vertebra is wanted, the iliac crests are placed in the center of the cassette. Locate junction of 5th lumbar vertebra and sacrum (which may be found 3 in. below the iliac crests) and mark with a fountain pen. Then locate the 1st lumbar vertebra and mark it in similar manner. Join the two points by drawing a straight line. Immobilize with compression band. Patient must breathe lightly during exposure.

Tube — Direct principal ray perpendicularly to the center of the line drawn between the first and fifth lumbar vertebrae, and to the center of the cassette.
Radiographic Technic — Measure thickness of part. Consult chart for lateral lumbar spine.
Kv.P. = (Cms. x 2) + 32.

(b) Projection Posterior (AP).
Landmark — Xiphoid process and symphysis pubis.
Film — 11 x 14, or 14 x 17. Use Bucky diaphragm.
Position — Patient lies on his back on the table, with his thighs flexed. Shift part into position so that the region between xiphisternum and pubic symphysis is at the center of the cassette. Immobilize with compression band, and have patient breathe lightly during exposure.
Tube — Direct principal ray perpendicularly to the center of exposure area.
Radiographic Technic — Measure thickness of part. Consult chart for lumbar spine.
Kv.P. = (Cms. x 2) + 32.

(2) *Part — Dorsal Spine.*

(a) Projection — Posterior (AP).
Landmark — Manubrium and xiphoid process of sternum.
Film — 14 x 17. Use Potter-Bucky diaphragm.
Position — Patient on his back on the table with body absolutely straight and shoulders in close contact with table.

For a view of the entire dorsal spine, center the film to 2 in. above the xiphoid process, which region falls between 6th and 7th dorsal vertebrae. Immobilize if necessary.

Tube — Direct principal ray perpendicularly to the center of exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for dorsal spine.
Kv.P. = (Cms. x 2) + 32.

(b) Projection — Lateral.
Landmark — 7th cervical and 12th dorsal vertebrae.
Film — 14 x 17. Use Potter-Bucky diaphragm.
Position — If the patient has a lateral curvature, he is placed on his side on the table with the apex of the curve nearest the table. Center the film to mid-region between 7th cervical and 12th dorsal vertebrae and to mid-axillary line. Immobilize by retention band, and have patient suspend respiration during exposure.
Tube — Direct principal ray perpendicularly to the center of exposure field.
Radiographic Technic — Measure thickness of part. Consult chart for dorsal spine.
Kv.P. = (Cms. x 2) + 32.

(3) *Part — Cervical Spine.*

(a) Projection — Posterior (AP).
Landmark — Hyoid bone.
Film — 8 x 10. Use Bucky diaphragm, if necessary.
Position — Patient on back with chin up, shift hyoid region over center of the film.
A view with patient sitting, or standing, may be taken by placing back of neck in contact with cassette, and hyoid region over the center of the film. Have patient hold his head in natural position.
Tube — Direct principal ray to center of exposure area and perpendicularly to film.
Radiographic Technic — Measure thickness of part. Consult chart for cervical spine.
Kv.P. = (Cms. x 2) + 32.

(b) Projection — Lateral.
Landmark — Hyoid bone.
Film — 8 x 10.
Position — Patient standing, or sitting, at vertical plate changer (or, lying on table), place shoulders against cassette-holding device. In vertical position, have the patient keep his head erect supported by a head-rest fastened to back of chair, or by a cardboard fastened to vertical cassette holder. Immobilize patient by means of a head band.
Tube — Tilt tube 90 degrees and direct principal ray at right angles to the center of the film placed in a vertical position.
Radiographic Technic — Measure thickness of part. Consult chart for lateral cervical spine.
Kv.P. = (Cms. x 2) + 32.

(4) *Part — Atlas and Axis.*

Projection — Posterior (AP).
Landmark — Odontoid process of the axis.
Film — 8 x 10.
Position — Patient lying on his back, place head on cassette supported on a 23 degree angle board. Shift head so that the external occipital protuberance is on the center of the

film. Sustain mouth open with a cork. Immobilize with compression band over fore-head, and have the patient suspend breathing during exposure.

Tube — Direct principal ray through the mouth perpendicularly to the center of the film.

Radiographic Technic — Measure thickness of part. Consult chart for cervical spine.

Kv.P. = (Cms. x 2) + 32.

Stereoradiography — Shift the tube 1.5 inches to either side from the center line and at right angles to the medial plane.

(5) *Part — Chest.*

Projection — Anterior (PA).

Landmark — 7th cervical and 12th dorsal vertebrae.

Film — 14 x 17.

Position — Patient in erect position, with anterior aspect of the chest against the vertical cassette changer. Move the cassette until the upper margin of the film is about 3 inches above the shoulders.

Have the patient rest his hands on his hips with head of humerus on either side rotated toward the film. Center the film to sixth spinous process (of the dorsal vertebra). Patient suspends breathing during exposure.

Tube — Direct principal ray perpendicularly to the center of the film.

Radiographic Technic — Measure thickness of part. Consult chart for chest.

Kv.P. = (Cms. x 2) + 32.

Stereoradiography — The shift (3 in. to either side from center) may be made either at right angles or parallel to medial plane.

(6) *Part — Sternum.*

(a) Projection — Anterior.

Landmark — Center of gladiolus.

Film — 8 x 10. Use Potter-Bucky diaphragm, if necessary.

Position — Patient lies in prone position on the table, with arms raised over his head. Immobilize with compression band, if necessary.

Place center of gladiolus over the center of the film.

Tube — Tilt tube 45 degrees inward toward medial line. Direct principal ray from the right side of the body to the center of the film.

Radiographic Technic — Measure thickness of part. Consult chart for sternum.

Kv.P. = (Cms x 2) + 30.

At 72 in., increase voltage 3 Kv.P.

(b) Projection — Lateral.

Landmark — Center of gladiolus.

Film — 8 x 10.

Position — Patient standing erect against the cassette changer with side of chest placed in close approximation of the cas-

sette, and arms extended over the head. Shift the film to the center of gladiolus. Immobilize, if necessary. Have patient suspend respiration during exposure.

This position shows from top to tip of gladiolus.

Tube — Direct principal ray perpendicularly to the center of the film.

Radiographic Technic — Measures thickness of part.

Kv.P. = (Cms. x 2) + 33. Distance — 72 inches.

MA-S = 13 with screens.

(7) *Part — Ribs.*

Projection — AP or PA.

Landmark — Point of most pain.

Film — 11 x 14, or 14 x 17.

Position — Shift the point of pain to the center of the film. Immobilize, if necessary. Have patient hold his breath during exposure.

Radiographic Technic — Measure thickness of part. Consult chart for sternum, or chest.

Kv.P. = (Cms x 2) + 30.

D. The Skull:—

(1) *Part — Head.*

(a) Projection — Frontal position (PA).

Landmark — Middle point of fronto-nasal suture, (Nasion).

Film — 8 x 10. Use 5 in. cone.

Position — Rest patient's fore-head and nose on cassette placed on an inclined plane of about 5 degrees from the horizontal. Shift nasion to the center of the film. Immobilize, if necessary.

Tube — Direct principal ray perpendicularly to the center of the film.

Radiographic Technic — Measure thickness of part. Consult chart for skull. Use Bucky diaphragm, if necessary.

Kv.P. = (Cms. x 2) + 36.

Stereoradiography — The shift may be made either at right angles or parallel with the medial plane.

Radiographic technic for AP projection is same as for PA.

Remarks: The radiograph will reveal the vertical plate of the frontal bone, frontalis, ethmoid, maxillary sinuses, bones of the face, and the mastoid process.

(b) Projection — Profile (lateral).

Landmark — Tip of nose.

Film — 8 x 10, or 11 x 14.

Position — Patient, seated in normal position near the table, hold the cassette against the side of head so that the anterior edge is parallel with median plane. The tip of nose is shifted 1½ inches from the edge of the film. The cassette is supported by the patient. See Fig. 193 for particulars.

Radiographic Technic — Measure thickness of part. Consult chart for head, or for use of cardboard technic.

Kv.P. = (Cms. x 2) + 36.

(c) Projection — Occipital (AP).
Landmark — External occipital protuberance.
Film — 8 x 10. Use 5 in. cone, and 1-mm Al filter.
Position — Patient lying on back, central occipital region centered to the cassette supported on a 25 degree block. Cone is placed against the head at a 15 degree angle toward the foot of the table. Have patient suspend respiration during exposure.
Tube — Direct principal ray to the saggital plane and just between and behind the frontal eminences.
Radiographic Technic — Measure thickness of part. Consult chart for head, and use Potter-Bucky diaphragm, if necessary.
Kv.P. = (Cms. x 2) + 36.
Remarks: The radiograph reveals occiput, foramen magnum, lambdoid suture, lateral blood sinuses, and a portion of air-sinuses.

(2) *Part — Sella Turcica.*
Projection — Lateral.
Landmark — Mid-region between canthus of eye and external auditory meatus.
Film — 8 x 10. Use 5-in. cone, and 1-mm Al filter.
Position — Support the cassette on a small platform or on a hard pillow at one end of the table. Have patient lie on his side with lateral aspect of his head in close approximation with the cassette. The height of the cassette from the table top must be such that the film will lie parallel to the saggital plane of the patient's head when placed over it.
Position head so that the mid-region of an imaginary line drawn from external auditory meatus to canthus of eye of same side falls on center of the film. Immobilize patient's head with retention band.
Tube — Direct principal ray perpendicularly to the center of the film.
Radiographic Technic — Same as for lateral view of head.
Kv.P. = (Cms. x 2) + 36.
Remarks: The radiograph reveals sella turcica (saddle-like depression) with the two anterior and posterior clinoid processes, lateral view of the sphenoidal and frontal sinuses, crista galli, the vomer, fronto-malar and zygomatico-malar sutures, coronal suture, superior and inferior maxilla, and contiguous structures.

(3) *Part — Jaw.*
Projection — Lateral.
Landmark — Mid-region of the jaw.
Film — 8 x 10. Use 1-mm Al filter.
Position — Patient lying on side with head on a 23 degree angle block, the shoulder is brought close to the head rest, and the head is tilted downward so that the principal ray may pass under the upper jaw.

If the ramus of the mandible is wanted, raise the chin off the film and place the posterior part of the jaw flat on the film.

If the anterior portion (body of mandible) is wanted, tip the chin down to the film.

Center mid-region of the jaw to the center of the cassette. Have patient hold his breath during exposure.

The posture for angle of mandible is shown in Fig. 192.

Tube — Direct principal ray to the mid-region of the jaw. If necessary, the tube may be tilted 5 to 10 degrees toward head.

Radiographic Technic — Measure thickness of part. Consult chart for jaw.

Kv.P. = (Cms. x 2) + 30.

Remarks: Radiograph reveals the structures shown in Fig. 192b.

(4) *Part — Mastoid Region.*

Projection — Lateral.

Landmark — Mastoid Region.

Film — 8 x 10. Use 5-in. cone, and 1-mm Al filter.

Position — Patient in lateral position on table with his head on a platform. Place external auditory meatus to the center of the cassette, and immobilize head.

Tube — Tilt tube 15 degrees toward the feet, and direct principal ray 2 inches above and 2 inches behind the external auditory meatus.

Radiographic Technic — Measure thickness of part. Consult chart for mastoid.

Kv.P. = (Cms. x 2) + 30.

(5) *Part — Optic Foramen.*

Projection — Semi-Lateral.

Boundary Landmark — Nasion, linea temporalis, anterior nasal spine, and zygomatic bone.

Film — 8 x 10.

Position — Patient lying in prone position, the orbit on the affected side is placed on the center of the cassette. The median plane of the head forms an angle of approximately 53 degrees with the horizontal. Immobilize with sand bag about the cervical region, or use retention band.

Tube — Direct principal ray perpendicularly to nasion with head placed on the 53 degree angle obliquely, or in a semilateral position.

Radiographic Technic — Use technic as for nasal sinuses.

Kv.P. = (Cms. x 2) + 30.

Remarks: The radiograph should reveal optic foramen, ethmoid sinuses, and contiguous structures.

(6) *Accessory Nasal Sinuses.*

(a) *Part — Maxillary Sinuses.*

Projection — Anterior (PA).

Landmark — Upper lip and junction of nose.

Film — 8 x 10. Use 5-in. cone, and (Bucky diaphragm).
Position — Patient lying in prone position on the table, with junction of nose centered to the film. Immobilize patient by pressing the open end of the cone against head.
Tube — Direct principal ray perpendicularly to the center of the film.
Radiographic Technic — Measure thickness of part. Consult chart for nasal sinuses.
Kv.P. = (Cms. x 2) + 30.

(b) *Part — Posterior Ethmoids.*
Projection — Anterior (PA).
Landmark — Eye-brows.
Film — 8 x 10. Use 5-in. cone, and (Bucky diaphragm).
Position — Patient lying prone on table, facial aspect of head toward film, shift head into position so that the canthus of eye and the external auditory meatus are on perpendicular line to the center of the film. Immobilize head by pressing with cone against it.
Tube — Direct principal ray perpendicularly to the center of the film.
Radiographic Technic — Measure thickness of part. Consult chart for nasal sinuses.
Kv.P. = (Cms. x 2) + 30.

(c) *Part — Frontal and Anterior Ethmoid Sinuses.*
Projection — Anterior.
Landmark — Eye-brows.
Film — 8 x 10. Use 5-in. cone.
Position — Patient lying prone on table, place head on cassette mounted on a 12 degree angle block. Center eye-brows to the center of the film. Immobilize head by means of cone.
Tube — Direct principal ray perpendicularly to the center of the film.
Radiographic Technic — Measure thickness of part. Consult chart for nasal sinuses.
Kv.P. = (Cms. x 2) + 30.

(d) *Part — Sphenoidal Sinuses.*
Projection — Anterior.
Landmark — Auditory Meatus.
Film — 8 x 10. Use 5-in. cone.
Position — Patient lying prone on table, place head on cassette mounted on 23 degree angle block. Place center region of open mouth to the center of the film. Immobilize head by means of cone.
Tube — Direct principal ray perpendicularly to the center of the film. The ray should pass through the plane of the external auditory meatus.
Radiographic Technic — Measure thickness of part. Consult chart for nasal sinuses.
Kv.P. = (Cms. x 2) + 30.

(e) *Part — Nasal Sinuses.*
Projection — Lateral View.
Landmark — External auditory meatus.
Film — 8 x 10. Use 5-in. cone.
Position — Patient lies on table with face on cassette placed on a small platform of same height as the shoulders. Position external auditory meatus to the center of the cassette. Immobilize, if necessary.
Tube — Direct principal ray perpendicularly to the film.
Radiographic Technic — Measure thickness of part. Consult chart for nasal sinuses.
Kv.P. = (Cms. x 2) + 30.

E. Standard Positions of Organs:—

(1) *Part — Heart.*
Projection — Anterior (PA).
Landmark — Acromion process, 12th dorsal vertebra, and xiphoid process of sternum.
Film — 14 x 17.
Position — Same as for chest.
Radiographic Technic — Measure thickness of part, and follow technic under "chest".

(2) *Part — Lungs.*
Projection — Anterior (PA).
Landmark — Acromion process, 12th dorsal vertebra, and xiphoid process of sternum.
Film — 14 x 17.
Position and Radiographic Technic — same as for chest.

(3) *Part — Gall Bladder.*
Projection — Anterior (PA).
Landmark — Dorsal spine and 10th rib.
Film — 8 x 10. Use 5-in. cone, and Bucky diaphragm.
Position — Patient lying prone on table, center film at region between 10th rib and dorsal spine, with the right thoracic quadrant in the field. Immobilize by having the patient suspend respiration during the exposure. Use rapid exposure technic.
Tube — Direct principal ray perpendicularly to the center of the film.
Radiographic Technic — Consult chart for gall bladder.
Kv.P. = (Cms. x 2) + 35.
Preparation of the Patient:—

1. About 6:00 o'clock in the evening, the patient takes with evening meal (fat free) one of Shadokol, Iodeikon, or Isoiodeikon, in a quantity according to the instruction of the radiologist. The administration will be facilitated if the preparation is mixed with grape juice or orange juice.
2. About 6:00 o'clock in the morning, the patient takes an enema, and omits breakfast.
3. Radiographic diagnosis is made at 8:00 o'clock in the morning.

4. Patient is given a fat meal (after the diagnosis) containing one-ounce of fat. About 4½ ounces of single cream will fulfill this requirement. (This causes the gall bladder to empty.)
5. A second radiograph is taken after 4 hours, or according to the physician's directions thereafter.

(4) *Part — Stomach.*

Projection — Anterior (PA).

Landmark — Determined by fluoroscopic examination.

Film — 8 x 10, or 11 x 14. Use adequate size cone, and Potter-Bucky diaphragm.

Position — Have patient stand before the vertical Potter-Bucky diaphragm. Slightly rotate the body of the patient to the right so that the shadow of the spine moves away from the field covered by the stomach. Center the fundus of the stomach to the film.

Tube — Direct principal ray perpendicularly to the center of the exposure area.

Radiographic Technic — Measure thickness of part. Consult chart for stomach. Use rapid exposure technic.

Kv.P. = (Cms. x 2) + 30.

Preparation of Patient:—

On an empty stomach, the patient is given a Barium meal consisting of 100 grams of Barium Sulphate in about 500 Cc of prepared malted milk, or buttermilk. Fluoroscopic examination starts during the administration of the meal to the patient standing erect between the fluoroscope and the vertical table top (shown in Plate II). When the entire stomach is located (preferably an outline drawn on the skin with a fountain pen), a radiograph is taken.

Six hours after this first examination, a second X-ray examination is made to determine the advance of the Barium meal through the gastro-intestinal tract, and also how much the stomach has emptied. Other radiological examinations are left to the discretion of the attendant radiologist.

(5) *Part — Gastro-Intestinal Tract (Stomach and Duodenum).*

Projection — Anterior (PA).

Landmark — Determined by fluoroscopic examination.

Film — 11 x 14, or 14 x 17. Use large cone, and Potter-Bucky diaphragm.

Position — Place patient on his abdomen on the table, with the region under examination centered to the exposure field. If examination is for the pyloric sphincters and duodenum, center this region to the field.

For examination of the entire intestinal tract, include in the field the xiphisternum above and pelvic region below. Immobilize patient by having him suspend respiration during exposure.

Tube — Direct principal ray perpendicularly to the center of the exposure field.

Radiographic Technic — Consult chart for gastro-intestinal tract. Use rapid exposure technic.

Kv.P. = (Cms. x 2) + 30.

Preparation of the Patient:—

If the examination is for the pyloric region and duodenum, or for any portion of the small intestine, the patient must take a Barium meal, and the radiograph must be made according to the direction of the radiologist. For a view of the colon, cecum, or appendix, the patient's bowels must be emptied and a Barium enema administered.

Subsequent radiographs are taken in accordance with the instructions of the attendant physician.

(6) *Part — Appendix and Cecum.*

Position and Technic — Same as for gastro-intestinal tract, except that center the mid-region of cecum to the field.

(7) *Part — Kidneys.*

Projection — Posterior (AP).

Landmark — Umbilicus.

Film — 14 x 17. Use large cone, and Bucky diaphragm.

Position — Have patient lie on his back over the table. Center the umbilicus to the film. The field of exposure should include symphysis pubis, and lower ribs. Immobilize patient, and have him suspend respiration during exposure.

Tube — Direct principal ray perpendicularly to the center of the exposure field.

Radiographic Technic — Consult chart for kidneys.

Kv.P. = (Cms. x 2) + 30.

Preparation of the patient:—

If the examination is for stones, the entire gastro-intestinal tract should be cleared by giving a dose of cathartic to the patient the night before, and cleansing the bowels with a physiological salt solution next morning previous to the examination. The visualization of the kidneys thus becomes greatly facilitated.

For exploration of the pelvis and calyces of the kidney, emulsified Ariodol (iodized and chlorinated peanut oil containing 27% Iodine and 7.5% Chlorine in chemical combination with glyceryl esters and fatty acids) is administered into the kidney by means of a catheter through the ureter. The preparation is radio-opaque, and, therefore, the apices of the renal pyramids converging toward the pelvis will be thrown into a marked contrast with contiguous structures, making the diagnosis of this region possible. (Catheterizing must be performed under the direction of the attendant physician.)

(8) *Part — Urinary Bladder.*

Projection — Posterior (AP).

Landmark — Umbilicus and Symphisis Pubis.

Film — 11 x 14. Use 5-in. cone, and Potter-Bucky diaphragm.

Position — Have the patient lie on his back, and center the

film to the region between the umbilicus and symphisis pubis. Immobilize patient by a compression band, and have him suspend respiration during the exposure.

Tube — Direct principal ray to the center of the film at 15 degree angle toward feet.

Radiographic Technic — Same as for kidneys.

Preparation of the patient:—

When examining for stones, the bladder is emptied to avoid secondary radiations due to urine content. The colon is cleansed with an enema previous to the examination.

To determine the size and the outline of the bladder, a 10% solution of Sodium Iodide must be catheterized into the bladder previous to radiographing this structure. A 5% solution of Skiodan (trade name) will also serve the purpose, producing less irritating effect.

F. Positioning For Pregnancy:—

(a) Projection — Posterior View.

Landmark — Xiphisternum and Symphysis Pubis.

Film — 14 x 17. Use large cone, and Potter-Bucky diaphragm.

Position — Patient lying on back on table, center the film to region between umbilicus and symphisis pubis. Immobilize patient by having her suspend respiration during exposure.

Tube — Direct principal ray perpendicularly to the center of the exposure field.

Radiographic Technic — Measure thickness of part. Consult chart for pelvimetry.

Kv.P. = (Cms. x 2) + 8.

Remarks:—The purpose of the radiograph is to show only the relation of the fetus to mother's pelvic outlet and not to the diameter of her pelvis.

This view, however, will give a general knowledge of the anatomical condition of the fetus, especially of its skeletal structure. The latter is not visibly defined in the radiograph of the fetus less than four months of development after conception. At any event, rapid exposure technic must be employed to eliminate movement of the fetus.

(b) Projection — Lateral View.

Landmark — Lower ribs and symphisis pubis.

Film — 14 x 17. Use large cone, and Potter-Bucky diaphragm.

Position — Patient lying on side on table, center the film to the region of the umbilicus. Immobilize patient by having her suspend respiration during exposure.

Tube — Direct principal ray perpendicularly to the center of the exposure field.

Radiographic Technic — Measure thickness of part. Consult chart for pelvimetry.

Kv.P. = (Cms. x 2) + 20.

3. Radiodontia.—Both the maxilla and the mandible contain alveolar borders which are excavated into cavities for the reception of the teeth.

PLATE VI

COMPARISON OF DIFFERENT PROJECTIONS OF THE CENTRAL RAY.*

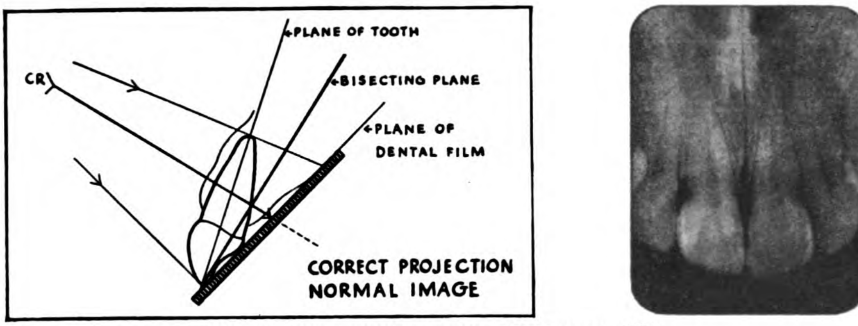


FIG. 1. LEFT, PROPER PROJECTION OF CR; RIGHT, IMAGE OF CORRECT SIZE.

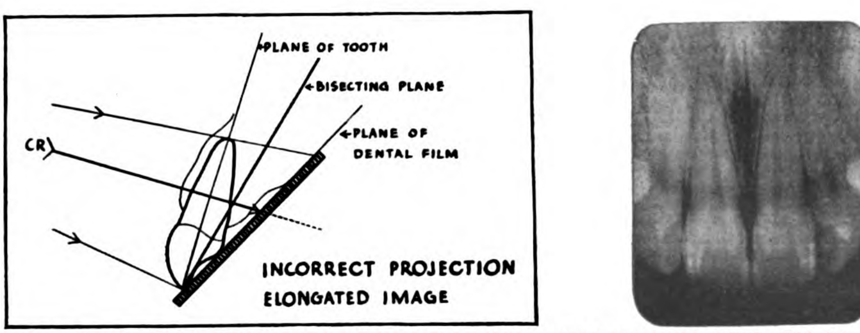


FIG. 2. LEFT CR PROJECTED FROM LOW ANGLE; RIGHT, ELONGATED IMAGE.

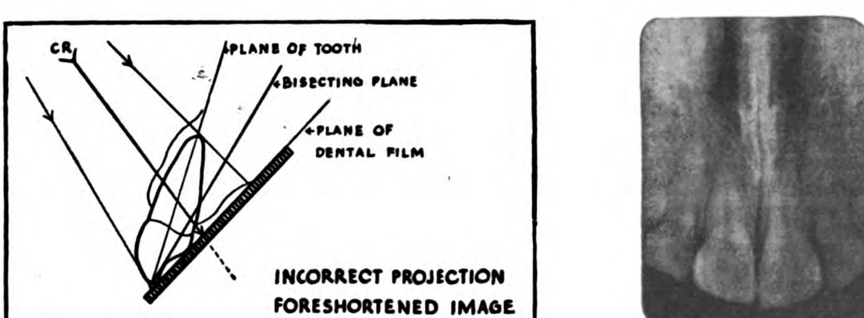


FIG. 3. LEFT, CR PROJECTED FROM HIGH ANGLE. RIGHT FORESHORTENED IMAGE.

*All subsequent illustrations are through the courtesy of Eastman Kodak Company, Medical Division.

These cavities vary in size according to the teeth they contain, and are lined with periosteum, which is continuous with the gums and serves to support the teeth in their sockets and affords nourishment. The principal function of the teeth is to comminute the food.

The average individual is naturally endowed with healthy teeth. But, this state may be altered as a result of improper food, systemic and nervous conditions, exposure of the gums to infection which in an advanced stage may attack the teeth from their apices, inability of the tooth to assimilate Calcium, and katabolic acceleration and putrefactive changes occurring in the structure of the tooth itself. In such an event, an ocular examination of the teeth supplemented by radiodontic methods offers the most effective means of ascertaining the condition of the inner tooth structure and the periapical relations of the teeth. Foreign bodies, impacted teeth, retained or infected roots, degenerative changes, lesions or other abnormalities are readily surveyed by a radiodontic diagnosis.

The purpose of dental radiography is preventive as well as preservative. It aims to preserve and prolong the normal life of the tooth by detecting and locating lesions and abnormalities at an early stage, and subsequently by eliminating the cause of such by proper treatment or repair. Periapical, occlusal, intra- and extra-oral examinations supplementary to ocular methods definitely aid toward realization of the ultimate in the remedying and preservation of the tooth.

A. The Teeth:—The teeth begin to appear in the human being about the sixth or seventh month, and usually by the end of second year the eruption of the *deciduous teeth,* numbering 20, is completed.

About the seventh year, the *permanent teeth* begin to replace the deciduous teeth; and, in the adult, there appear 32 permanent teeth, 16 in each jaw. They are divided as follows:

Left–	Molar	Pre-molar	Cuspid	Incisor	Cuspid	Pre-molar	Molar –Right
Upper –	3	2	1	4	1	2	3
Lower –	3	2	1	4	1	2	3

Each tooth consists of one or more *roots* or *fangs* occupying an *alveolus,* a constricted portion, called the *neck,* and the *crown,* which is exposed beyond the level of the gums.

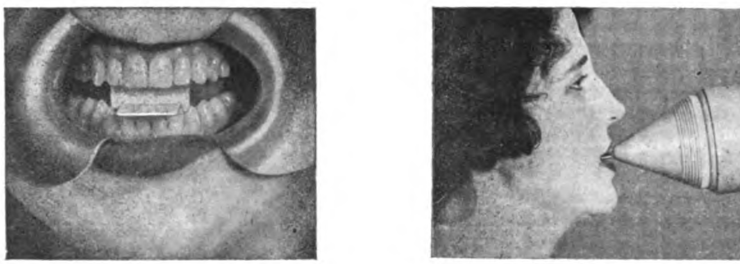
In structure, a tooth consists of an outer dense layer, the *enamel,* encasing the crown; the *dentine,* whose crown portion is covered by enamel and the root portion by *cement;* and the *pulp,* which is a soft vascular tissue filling the *pulp-cavity* below the crown. Continuous with the pulp-cavity is a *central canal* which permits the passage of blood vessels and nerves to supply the tooth.

The danger of bacteria formation due to food particles and improper cleansing of the teeth appears to be ever-present, and when such is the case, there is a formation of acid fermentation which tends to react with the enamel or dentine, resulting in the decaying of the tooth and formation of cavities. Proper oral and dental cleansing together with proper choice of food eaten considerably aid to promote the hygienic condition of the teeth, preventing decay and infection.

B. Radiography of The Teeth and Contiguous Regions:—

(1) *Interproximal Radiography.*—Interproximal radiographic records reveal the conditions of the coronal two-thirds of the teeth, Figs. 183 and 185, and are valuable in the detection of decay, degenerative changes in the pulp, and local irritations due to faulty dental work and secondary deposits.

This type of radiograph is made on a *Bite-Wing* film, which consists of a single film, a lead backing, white moisture-proof paper covering and a centrally disposed wing on which the patient bites to hold the film in proper position, Figs. 184 and 186. The packets are made in various sizes to be used according to the teeth radiographed.



(A) (B)
FIG. 183. (A) ILLUSTRATING THE MANNER OF INSERTING THE FILM, AND (B) ALIGNMENT OF THE X-RAY TUBE WITH THE FILM.

FIG. 184. BITE-WING RADIOGRAPHS OF ANTERIOR REGIONS SHOWN IN FIGS. 183A AND B.

The radiographic procedure for *Bite-Wing* films consists of placing the packet (in a definite region wanted) parallel with the long axis of the teeth and holding it horizontally between the occluded teeth. The principal ray is directed through the interproximal spaces and at about 8 degrees above the occlusal plane positioned horizontally. The exposure factors for Eastman Bite-Wing type films are given in Table XVII.

(2) *Periapical Radiography.*—Dental profession highly favors the examination of periapical regions as an index to the disclosure of the hidden abnormalities involving the areas in and about the apices of the teeth and their contiguous tissues. Previous to such an examination, a dentist seldom attempts to institute treatment. A thorough radiodontic examination consists of knowledge derived from clinical, interproximal, and periapical

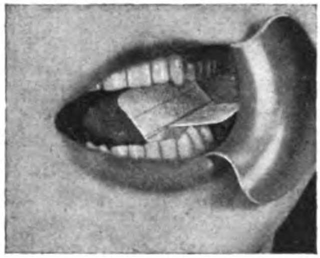



FIG. 185. POSTERIOR BITE-WING TECHNIC.


(A) (B)

FIG. 186. (A) BITE-WING RADIOGRAPH OF PREMOLAR SECTION OF POSTERIOR REGION, AND (B) BITE-WING RADIOGRAPH OF POSTERIOR REGION OF PREMOLARS AND MOLARS.

Table XVII:—Exposure Chart For Bite-Wing Technic.

Region	Film	Average Vertical Angle	Exposure Adult	Exposure Child
Incisors	Type 1	+ 8°	3 seconds	1½ seconds
Incisors-Premolars	Type 1	+ 8°	3 seconds	1½ seconds
Premolars-Molars	Type 3	+ 8°	5 to 6 seconds	3* seconds

50 *Kv.P.*, 10 MA, and 8 inches.

*Special No. 0 size Bite-Wing type film.

records which serve as a basis for determining the procedure to be followed.

The technic for periapical radiography described in this text is based on the use of a minimum of fourteen films for the adult—seven for the upper jaw, and seven for the lower one. The arrangement is as follows:

UPPER	Molars	Pre-Molars	Cuspid-Lateral Incisors	Centrals Incisors	Lateral Incisors -Cuspid	Pre-Molars	Molars
Film –	1	1	1	1	1	1	1
LOWER							
Film–	1	1	1	1	1	1	1

Periapical films of various manufacture are now commercially available and many of these serve the purpose quite satisfactorily. The most popular of the type, however, is the Eastman Radia-Tized films, which are wrapped in white, sanitary, moisture-proof paper, and backed with sheet lead. The films are coated on both sides, affording desirable radiographic qualities and wide exposure latitude.

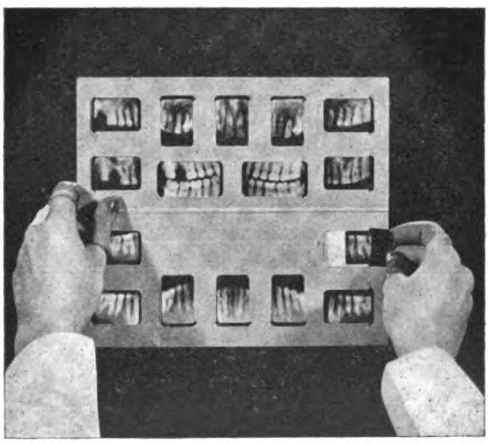
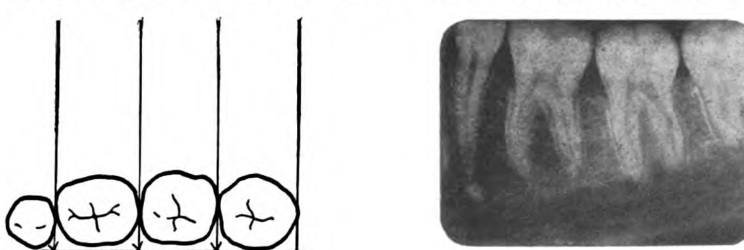


FIG. 187. MOUNTING PERIAPICAL RADIOGRAPHS.

There is embossed on each film a dot which serves as a convenient regional identification of the radiograph — the raised side indicating the parietal aspect, and the depressed side the oral cavity. On the outside surface of the packet, there is a printed dot to correspond with the pebble of the film. In inserting the individual packets, the side bearing the mark should be placed adjacent to the buccal aspect of the teeth and nearest to their apical region. Careful observance of these instructions saves time and unnecessary annoyance when identifying and mounting the films in appropriate dental mounts, Fig. 187.

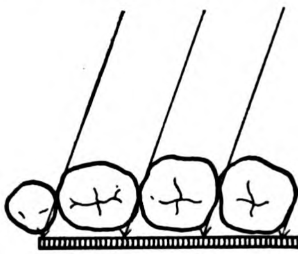
In positioning the film packet in place, it is essential that bending or shaping of the film to make it conform to the dental arch is avoided in



(A) (B)

FIG. 188. (A) CORRECT HORIZONTAL PROJECTION OF THE PRINCIPAL RAY, AND (B) RESULTING RADIOGRAPH OF DISTINCT IMAGE WITH FINE DEFINITION.

order to eliminate by far the distortion thus produced. The principal ray must be projected perpendicularly to an imaginary plane formed at the bisector of the angle between the plane of the film and the long axis of the teeth. Fig. 188a shows the correct horizontal projection of the principal



(A)

(B)

FIG. 189. (A) INCORRECT HORIZONTAL PROJECTION OF THE PRINCIPAL RAY, AND (B) RESULTING RADIOGRAPH WITH OVERLAPPING IMAGE.

ray with the resulting radiograph shown in Fig. 188b, while the radiograph in Fig. 189b illustrates the result of incorrect horizontal projection (Fig. 189a) of the principal ray.

The exposure factors for periapical radiography using Eastman Radia-Tized dental X-ray films are given in Table XVIII below.

Table XVIII:—Exposure Chart For Periapical Radiography.

Region	Vertical Tube Angle	Exposure Time* for Adult
UPPER		
Incisors........................	+ 40°	3 seconds
Cuspid........................	+ 40°	2½ seconds
Premolars........................	+ 35°	3 seconds
Molars........................	+ 30°	4½ seconds
LOWER		
Incisors........................	− 15°	2 seconds
Cuspid........................	− 20°	2½ seconds
Premolars........................	− 10°	2½ seconds
Molars........................	− 5°	3 seconds

*For children, the time of exposure is reduced to approximately half of the values given above.

Average Voltage = 55 Kv.P., Tube Current = 10 MA

Anode-Film Distance = 8″

Processing:—5 minutes at 65° F. Also, consult Chart in Figure 175.

To protect the dental X-ray films from extraneous radiations in the exposure room, convenient containers made of ray-proof metal are of distinct advantage. The dental film dispenser in Fig. 190 holds a gross standard-size packets easily accessible to the operator. A plunger mechanism delivers the individual packets one at a time when a slight pressure is exerted on it. The dispenser may be mounted in a convenient position on the wall.

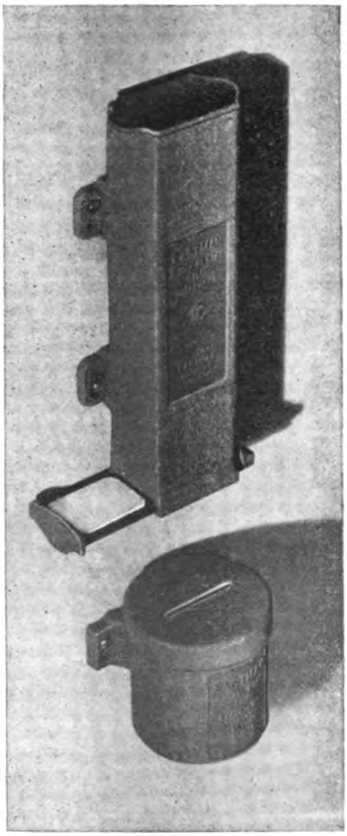
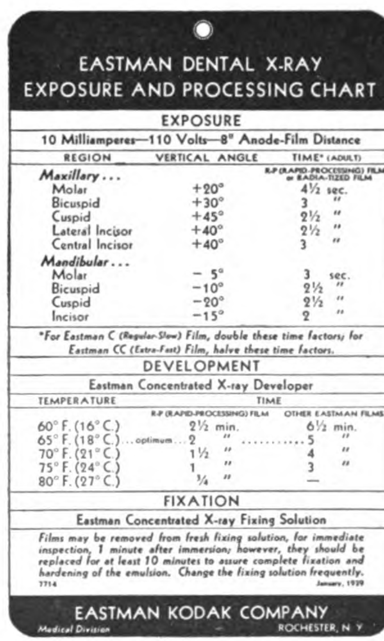


FIG. 190 EASTMAN DENTAL FILM DISPENSER WITH RECEPTACLE



EASTMAN DENTAL X-RAY
EXPOSURE AND PROCESSING CHART

EXPOSURE

10 Milliamperes—110 Volts—8" Anode-Film Distance

REGION	VERTICAL ANGLE	TIME* (ADULT) R-P (RAPID-PROCESSING) FILM or RADIA-TIZED FILM
Maxillary . . .		
Molar	+20°	4½ sec.
Bicuspid	+30°	3 "
Cuspid	+45°	2½ "
Lateral Incisor	+40°	2½ "
Central Incisor	+40°	3 "
Mandibular . . .		
Molar	− 5°	3 sec.
Bicuspid	−10°	2½ "
Cuspid	−20°	2½ "
Incisor	−15°	2 "

**For Eastman C (Regular-Slow) Film, double these time factors; for Eastman CC (Extra-Fast) Film, halve these time factors.*

DEVELOPMENT

Eastman Concentrated X-ray Developer

TEMPERATURE	TIME R-P (RAPID-PROCESSING) FILM	OTHER EASTMAN FILMS
60° F. (16° C.)	2½ min.	6½ min.
65° F. (18° C.) . . . optimum . . .	2 "	5 "
70° F. (21° C.)	1½ "	4 "
75° F. (24° C.)	1 "	3 "
80° F. (27° C.)	¼ "	—

FIXATION

Eastman Concentrated X-ray Fixing Solution

Films may be removed from fresh fixing solution, for immediate inspection, 1 minute after immersion; however, they should be replaced for at least 10 minutes to assure complete fixation and hardening of the emulsion. Change the fixing solution frequently.

7714 January, 1939

EASTMAN KODAK COMPANY
Medical Division ROCHESTER, N. Y.

EASTMAN TIME-TEMPERATURE DEVELOPMENT CHART.

After the exposure, the packets are carefully dried with a towel and dropped into a ray-proof receptacle, Fig. 190, which may be fastened by screws near the film dispenser.

(3) *Intra-Oral, Extra-Oral, and Profile Radiography.*—Since the purpose of interproximal and periapical radiography is to concentrate on specific areas with the view of determining the conditions attendant only to the apices and crowns, and their contiguous tissues, frequently it becomes desirable to supplement the examination with radiographs of occlusal regions in order to obtain a wider survey of the teeth in conjunction with

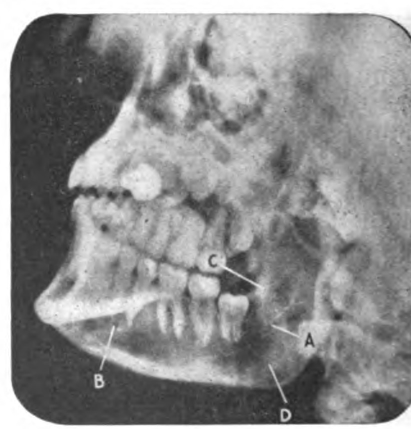
the two maxillae. Fractures of the jaw, foreign bodies, degenerative changes in the edentulous areas, infections at or about the roots of the teeth, and other anomalies are readily visualized and accurately localized by occlusal examination.

FIG. 191. PLACEMENT OF INTRA-ORAL CASSETTE.

An occlusal view of a specific region of either jaw may be had using Eastman Super Speed occlusal film mounted in an intra-oral single-screen cassette. The manner of insertion of the cassette in mouth is shown in Fig. 191. The smooth face of the cassette is placed against the occlusal surface in correct alignment with the tube, and retained by the patient's bite.

Extra-oral views of both the maxilla and the mandible are of decided aid in the augmenting of the examination, and these are generally made on an 8 x 10 X-ray film mounted in an exposure holder with or without intensifying screens. Fig. 192 illustrates the technic of positioning, in which the side to be radiographed is in flat contact with the center of the cassette, and the principal ray is directed from behind and beneath the mandibular angle at 25 degrees above horizontal.

(A) MANNER OF POSITIONING PATIENT'S PART.



(B) THE RESULTING RADIOGRAPH FROM (A).

FIG. 192. EXTRA-ORAL RADIOGRAPH OF THE TEETH, MAXILLA, MANDIBLE, AND CONTIGUOUS EDENTULOUS STRUCTURES.

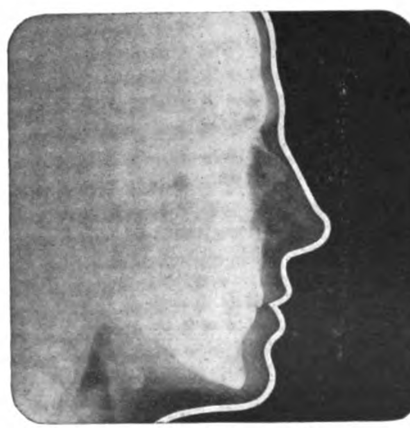
The radiograph in Fig. 192b presents the *angle of mandible*, posterior portion of *maxilla*, *coronoid process*, *mandibular canal* (A), *mental foramen* (B), *external oblique line* (C) terminating in anterior border of *ramus*, and *mylohyoid groove* (D) for submaxillary gland.

There is still another method which serves the more specific purpose of detection and correction of malocclusion of the teeth. A profile radio-

graph made previous to a prosthetic surgery, or to the correction of malformations such as straightening the teeth, widening oral arches, and restoring jaws to proper shape (orthodontia), and other abnormalities as may be associated therewith, becomes of undisputed value because of the definite record that it presents of the soft tissue profile together with the natural relationship of the bony structures to guide the prosthetist in restoring the original facial contour. The restored profile is compared with a second radiograph of similar position after the denture is completed. This establishes confidence of the patient, and annoyance from complaints or pursuant law suits is thus avoided.

The standardized technic for profile method is illustrated in Figs. 193a and 193b. The patient is seated in the dental chair, with head in normal position, and a cassette placed against the side of head and slightly in front of the facial profile. The cassette rests on patient's shoulder and is supported with hand on the same side, while the other hand holds the lower anterior corner. The tube is tilted to a horizontal position, and the principal ray is directed perpendicularly to the cassette.

(A)



(B)

FIG. 193. (A) PLACEMENT OF CASSETTE FOR PROFILE TECHNIC, AND (B) THE RESULTING RADIOGRAPH.

Radiographic Technic — Measure thickness of part, and consult chart (Table XVI) for lateral view of head.

Kv.P. = (Cms. x 2) + 32.

C. Procssing Room.—Much has already been said as regards the requirements of a radiographic processing room. A model dental processing room with equipment essential for complete dental processing work is shown in Plate V.

APPENDIX VI

ROENTGEN THERAPY

It has been already pointed out that X-rays have definite influence upon living tissues, that moderate dosages may accelerate the life cycles of the cells while excessive amounts tend to produce erythematous effects or necrosis of the cells. The chief determinant as to whether the cellular degeneration will occur in the superficial or in the deep-lying tissue structures is the effective wave-lengths of the roentgen rays. Indeed, various tissues present varying degrees of sensitivity to the radiation—leukocytes exhibiting the most radiosensitive characteristics whereas fat cells are affected the least by X-rays. (See Section 2, Chapter XX.)

Moderate exposure of the living cells to X-rays is not harmful, but irradiating the cells indiscriminately is to render the cell membrane more permeable that the absorption of water by the cell with a consequent diminution in the concentration of the cell plasma and in the osmotic pressure are brought about. The condition gives rise to hemolysis of the erythrocytes and to the decrease in the number of leukocytes in the body. Other conditions, such as the constriction of the capillary vessels, inhibition of enzymatic secretions, retardation of glandular functions, and disintegration of the cells, are prevalent as consequence to excessive exposures to X-rays. Hence, the application of roentgen rays to treating the living tissues should be supervised by a competent roentgenologist in order that benefit may be derived from the treatment.

The degree of absorption of X-rays by matter is approximately proportional to the atomic weight of the substance. In living tissues the extent of this effect is further dependent upon individual sensitivities and on the manner the radiation is applied. That is, the biological dose, or erythema reaction, for various individuals can be established by determining the number of r required to cause the reddening of the skin one week after the exposure. This dose is specific for each individual and is measured in r. The instrument that records this measure is known as the Mecapion, shown in Fig. 194.

It should be kept in mind that the number of r required to produce an erythema reaction varies with treatment period; viz., if the dosage is given over a long period of time the number of roentgens required to produce a specific skin reaction will be greater than when the treatment is administered at one dose. Moreover, with radiations incited by higher kilovoltages (above 200 Kv.P.) a greater number of roentgens are used than with those produced at lower kilovoltages, since the radiations at higher kilovoltage ranges are not easily absorbed by the tissues. The erythema time is given in the following convenient expression:

$$T_e = \frac{t \times r}{K \times 60} \text{ minutes}$$

where t is the discharge time in seconds (of the ionization chamber), r is the number of roentgens required to produce an erythema, and k is a constant of the instrument in r per full scale deflection.

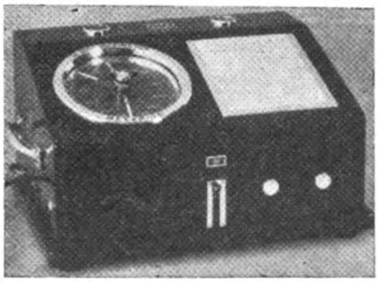
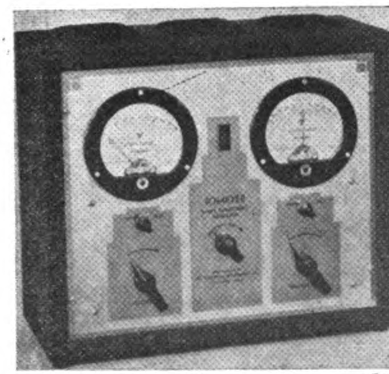


FIG. 194. THE MECAPION WHICH MEASURES X-RAY INTENSITIES IN R.



(COURTESY GENERAL ELECTRIC X-RAY CORP.)
FIG. 195. THE IOMETER.

Since the radiation emanating from the target of the X-ray tube consists of heterogeneous wave-lengths, it must be filtered before it is applied in treatment. For this reason, it is important that adequate selection be made of a filter which delivers rays most effective to the area of treatment but least harmful to the superficial structures. Copper sheets of varying thicknesses (0.5 to 2 mm), and Aluminum, or the combination of the two, are used, depending on the quality of radiation desired and on the depth of dosage. Copper is found to be more radiotransparent to soft radiations while Aluminum is more transparent to hard rays. The combination, therefore, will offer an excellent filteration at desired radiation quality. Pulsating voltages, however, require more filteration than continuous voltages.

In deep therapy, a high intensity of the incident radiation with as little an effect to the skin and intermediate tissues as possible becomes of great importance; hence, the use of high kilovoltage. That the intensity of the unfiltered X-radiation varies in accordance with the equation

$$I = \frac{Kv^2 \times M.A.}{d^2}$$

is far from the actual case, in that, the exponent of (Kv) varies widely with different applied tensions to the tube, and that the atmospheric relations, the type of apparatus, and the condition of the part irradiated become contributing factors of this divergence.

While surface intensity varies in accordance with equation (125)

$$I \propto \frac{1}{d^2}$$

a more uniform distribution will be obtained as the focal distance becomes greater; and hence, the depth intensity expressed in percentage of the surface intensity will accordingly increase. The usual distance varies between 25 to 50 cms, depending on the location and size of the tumor and on the condition of the patient. When it is desired to obtain a high percentage depth dose larger exposure fields are selected because of the increased surface intensity. For instance, an increase of approximately 25% in the surface intensity may incur by varying the field from 5 x 5 cms to 20 x 20 cms.

Since in directing the X-rays from a single port to the malignant tissue in the deep-lying structures there will be a tendency for some of the normal tissues superficial to this area of treatment to become affected, an improved method, known as *"multiple-firing"* or *"cross-firing"*, consists of directing the radiation from several portals of entry so that while the diseased tissue receives a large dosage the surface distribution at the portal is within the permissible dosage of the skin.

To elucidate this further, if an area of 5 cms below the surface of the skin receives 50% of the surface dose, and it requires 100% dosage for an effective treatment of this area, then by directing the X-ray beam from a single portal the surface radiation distribution in giving a 100% depth dosage will be 200%, and, accordingly, severe dermatitis will result in the normal portal tissue. To avoid such a consequence, the radiation is directed simultaneously, from two independent X-ray tubes, through two opposite portals, with consequent shortening of the exposure time. Thus, the tumor receives 50% from each of the two portals—a total of 100% dose—while the skin at each port of entry receives 100%. If four X-ray tubes are used in cross-firing positions, the time of the exposure will be halved, and the tumor cells will receive 25% of the full dose from each portal, while the surface distribution dose will be only 50%. In practice, full dosage at any one time is not advisable, but it is given in a series of small doses.

The treatment of benign skin conditions (superficial therapy) may be accomplished by irradiating the affected part with radiations (filtered or unfiltered) incited by 90 to 140 kilovolts with 4 to 5 milliamperes, using a broad focus tube. The focal-skin distance usually ranges from 9 to 12 inches. Superficial therapy is generally accepted as an aid in improving the condition of skin inflicted with Acne, Eczema, Psoriasis, Pruritis, Ringworm, Sycosis, Moles, Keratosis, and other superficial lesions.

In the administration of deep therapy, it is highly desirable that the operator be supervised by an attendant roentgenologist competent in the profession. Previous to the treatment, a thorough history of the patient, including the location and type of the tumor and the patient's general condition at the time of treatment, should be had and carefully considered. Haphazard treatment is not only injurious to the patient but also to the science of radiation therapy.

The malignant diseases most commonly treated in deep therapy are Cancer of various body structures, Parotid Tumors, Carcinoma of the Breast, Abdominal Tumors, Brain Tumors, Leukemia, Idiopathic Bleeding, etc. The kilovoltage used for this purpose varies from 200 KV to several million volts, depending on the discretion of the therapist and the equipment available.

During the treatment of the patient, the *"thimble"* chamber of the Mecapion (ionization chamber of a few centimeters cube in volume) is placed on the area under treatment or is inserted in the body cavities. The dosage is regulated by turning an indicator on the Mecapion to the required point. During irradiation, the indicator moves back in steps of 2.5 r until the whole dose is applied, when, the X-rays are automatically shut off.

The radiation exposure is expressed in r per minute. Thus, for a discharge time of, for instance, 20 seconds, if the calibration of the instrument is 4-r per full scale deflection of the indicator, we may express the dose per minute by

$$D_m = \frac{K \times 60}{t}$$

$$= \frac{4 \times 60}{20} = 12\text{-r per minute.}$$

In the above equation K is the calibration constant of the instrument in roentgens per full scale deflection, and t is the discharge time in seconds.

APPENDIX VII

Questions and Answers to Help Students Prepare Themselves To Take Civil Service Examinations and Those Given By The American Registry of X-Ray Technicians.

SECTION I

ATOMIC THEORY & RADIATION

1. (Q). What is matter?
   (A). Matter is that which occupies space, and is perceptible by the physical senses. It is composed of very small unit quantities called molecules, or, atoms. Examples:—A book, air, water, salt, etc.
2. (Q). What is a molecule?
   (A). The smallest unit quantity of matter which can exist by itself and can retain all the characteristics of the original substance is called a molecule. Examples:—Water, Oxygen, Table salt, Nitrogen, Iron, etc.
3. (Q). What is an atom? In what states can an atom exist?
   (A). The smallest structural unit of elementary matter which can enter into a chemical reaction. Examples:—Oxygen, Neon, Chlorine, Zinc, Iron, etc. An atom can exist in the form of a gas, liquid, or solid.
4. (Q). What is the structure of an atom?
   (A). An atom consists of a central core called the nucleus containing positive and negative charges. All of the positive charges, known as protons, are in the nucleus, and approximately half of the total number of negative charges known as electrons, are in the nucleus, and the remaining half are outside the nucleus, revolving in definite orbits around it. In a normal atom there are as many protons as there are electrons.
5. (Q). When is an atom at rest (neutral)? When ionized?
   (A). An atom is at rest or neutral when it has as many negative charges as it has positive charges. An atom is ionized when it has lost one or more electrons.
6. (Q). What is the mass of a proton?
   (A). The mass of a proton is 1.649×10^{-24} gram; or, it is 1845 times as heavy as the electron.
7. (Q). What is the mass of an electron?
   (A). The mass of an electron is 9.03×10^{-28} gram; or, it is equal to 1/1845th that of proton.
8. (Q). What charges can move in an electric conductor?
   (A). In an electric conductor only the electrons move in an axial direction.
9. (Q). What is an ion?
   (A). Either a positive or a negative charge may be called an ion.
10. (Q). Is an electron called an ion? What kind?
    (A). An electron is also known as a negative ion.
11. (Q). What are five important characteristics of an electron?

(A). 1. The speed of an electron may vary between 1/20th to full speed of light.
2. An electron may be deflected by a magnetic or an electric field.
3. All electrons are negatively charged and are alike.
4. An electron can affect the emulsion of a photographic film.
5. An electron can be made to transfer energy from one medium to another.

12. (Q). What is electricity?
(A). The migration of electrons in an electric conductor is known as a current of electricity.

13. (Q). In what two processes do electrons leave the surface of a metallic conductor?
(A). Electrons leave the surface of a metallic conductor in the process of 1. Thermionic emission, and 2. Photoemission.

14. (Q). What is thermionic emission? What are thermions?
(A). Escape of electrons from metals heated to high temperatures is known as thermionic emission. The electrons thus emitted are known as thermions.

15. (Q). What is photoelectric emission? What are photoelectrons?
(A). The process in which light waves falling on matter and causing electrons to be given off from its surface is known as photoelectric emission. The electrons thus emitted are called photoelectrons.

16. (Q). What is meant by excitation of an atom?
(A). When an electron in an atom moves from its original orbit to some other orbit, the atom is said to be in an excited state, and the process is known as excitation.

17. (Q). What phenomenon follows the excitation of an atom?
(A). Radiation follows the excitation of an atom.

18. (Q). What is radiation?
(A). In an excited atom, as the electron returns to its original orbit an emission of light, or radiation ensues.

19. (Q). What is a photon? A quantum of light?
(A). A photon or a quantum of light is the unit quantity of light that ensues a single radiation of an electron.

20. (Q). What is potential or voltage?
(A). The electrical force which causes electric charges to move is known as voltage or potential.

21. (Q). What is ionization potential?
(A). The least potential or voltage required to remove an electron out of the atom.

22. (Q). What is excitation potential?
(A). The minimum potential required to remove an electron from one orbit to another in the same atom is referred to as the excitation potential for that electron.

23. (Q). What is kinetic energy?
(A). When a matter particle is in motion it requires an energy of motion known as kinetic energy.

24. (Q). What is an anode? What is a cathode?
(A). The positive electrode in a discharge tube is called an anode, and the negative electrode is called a cathode.

25. (Q). What name is given to the stream of electrons leaving the cathode in a discharge tube?
    (A). Cathode rays.
26. (Q). What energy does the electron possess as it leaves the cathode of a discharge tube?
    (A). The electron, as it leaves the cathode, possesses voltage energy equal to Ve/300 ergs.
27. (Q). What is the speed of light?
    (A). 30,000,000,000 cms per second.
28. (Q). What is meant by the wave-length of a radiation?
    (A). Since radiation is said to propagate in wave motion, the straight line distance between any two successive corresponding points on a single wave is known as the wave length for that radiaton.
29. (Q). What is meant by the frequency of a radiation?
    (A). The number of recurrences of complete waves (cycles) per second is known as the frequency of that radiation.
30. (Q). How is the wave-length of a radiation related to its frequency?
    (A). The wave length of a radiation is equal to the speed of light (30,000, 000,000 cms.) divided by the radiation frequency.
31. (Q). What is meant by electromagnetic wave?
    (A). An electromagnetic wave is a train of disturbance created in space by the radiation of an electron.

SECTION II

MAGNETISM

1. (Q). What is magnetism?
    (A). The property of iron attracting bits of particles to itself is known as magnetism.
2. (Q). What are natural magnets?
    (A). Magnets, such as lodestones found in natural forms, are known as natural magnets.
3. (Q). What are artificial magnets?
    (A). Magnets made by artificial means are known as artificial magnets.
4. (Q). How are artificial magnets produced?
    (A). Iron, steel, or their alloys subjected to electric or magnetic fields become magnetized.
5. (Q). Through what substances can magnetic force act?
    (A). Magnetic force can act through almost any substance.
6. (Q.) How many poles has a magnetized bar of iron?
    (A.) Two poles—a north pole, and a south pole.
7. (Q.) What kind of metals are best suited for the manufacture of temporary magnets? Why?
    (A). Soft iron and its alloys are best suited for the manufacture of temporary magnets, because the soft iron can lose its magnetism as soon as the magnetizing force is removed.
8. (Q). What kind of metals are best suited for the manufacture of permanent magnets? Why?

(A). Hard iron, and steel, and an alloy of aluminum, nickel, and cobalt. These metals can retain their magnetism after the magnetizing force is removed.

9. (Q). What is a magnetic compass?
   (A). The instrument consisting of a magnetized steel needle to indicate geographical directions is known as the magnetic compass.
10. (Q). Give some applications of temporary magnets.
    (A). Temporary magnets are used in the solenoids of electric door bells, transformers, electric door locks, telegraph keys, etc.
11. (Q). Give a few applications of permanent magnets.
    (A). Permanent magnets in the shape of horse-shoes are used in electric dynamos, telephone receivers, speedometers, etc.

SECTION III

DYNAMIC CURRENTS

1. (Q). What is electricity?
   (A). A stream of electrons flowing through an electric conductor constitutes a current of electricity.
2. (Q). How is electricity produced? What is the device producing it called?
   (A). When a coil of wire is moved rapidly in a magnetic field, a current of electricity is the result. The device producing electricity is known as an electric generator.
3. (Q). What is static electricity?
   (A). Stationary electric charges constitute static electricity.
4. (Q). What is dynamic current?
   (A). When electric charges such as electrons are made to move in a conductor, a dynamic current is the result.
5. (Q). What are the electrical factors entering into the generation and transmission of electricity?
   (A). Voltage, amperage, ohmage, and wattage.
6. (Q). What is electromotive force or voltage? What is a kilovolt?
   (A). The electrical force to cause the electrons to flow in a conductor is known as the voltage. A kilovolt is one thousand volts.
7. (Q). What is an ampere? What is a milliampere?
   (A). An ampere is a unit of current flowing per second. A milliampere is one-thousandth of an ampere.
8. (Q). What is an ohm? What is a megohm?
   (A). An ohm is a unit of electrical resistance. A megohm is one million ohms.
9. (Q). What is a watt? A kilowatt?
   (A). A watt is a unit of electrical power. A kilowatt is one thousand watts.
10. (Q). What is the difference between power and potential?
    (A). Electric power is the combined energy of both the potential and the current, while potential is the electrical force causing the current to flow in a wire.
11. (Q). State Ohm's law, and give the formula.
    (A). The flow of current in a conductor is directly proportional to the potential (E.M.F.) and inversely proportional to the resistance of the

conductor. $I = V/R$ and $V = IR$.

12. (Q). What is a unit of heat called?
    (A). One gram-calorie, or simply a calorie.
13. (Q). What types of wires are used for producing heat from electric currents?
    (A). Iron, steel, tungsten, nichrome, chromel, etc.
14. (Q). What is an electric fuse? What is it made of?
    (A). An electric fuse is a metal which melts and breaks the circuit when the current flow exceeds the rated capacity of the fuse. It is made of sheet zinc, tin, aluminum, or mercury.
15. (Q). What is direct current? Give examples.
    (A). A direct current is one in which the current flows always in one direction. Either a storage battery or a dry cell furnishes a direct current.
16. (Q). What is an alternating current?
    (A). An alternating current is one in which the current alternately changes its direction of flow.
17. (Q). What is the speed of an electric current?
    (A). An electric current flows in a wire with the speed of light.
18. (Q). What is meant by the wave-length of an alternating current?
    (A). Since the rising and falling of the intensity of an alternating current may be represented by a wave form, the straight line distance between any two corresponding points or successive waves represents a wave-length of the current.
19. (Q). What is meant by the frequency of an alternating current?
    (A). The number of repeated occurences of waves per second is known as the frequency of that current.
20. (Q). What is meant by "cycle" as applied to alternating currents?
    (A). A cycle is a unit of frequency constituting a complete A.C. wave.
21. (Q). What is an alternation as applied to A.C.?
    (A). An alternation is half of a cycle, or one impulse.
22. (Q). How many alternations are there in 25 cycle, 50 cycle, 60 cycle, and 500 kilocycle currents?
    (A). There are 50 alternations in a 25 cycle current; 100 alternations in 50 cycles; 120 alternations in 60 cycles; and one-million alternations in 500 kilocycles.
23. (Q). Give the formula for finding the wave-length of a given alternating current.
    (A). Wave-length = speed of light ÷ frequency of current.
24. (Q). Give the formula for finding the frequency of a given alternating current.
    (A). Frequency = speed of light ÷ wave-length of current.
25. (Q). What does the sine wave of an alternating current indicate?
    (A). The sine wave of an alternating current is the graphical representation of the rising and falling of the intensity of that current.
26. (Q). What metal is generally used in transmitting current?
    (A). Copper.
27. (Q). What is the relation of the size of the wire to loss of power during transmission?
    (A). The larger the diameter of the transmitting wire, the smaller the power loss, and vice versa.
28. (Q). Why is electricity transmitted at high voltage?
    (A). In order to reduce power loss to a minimum.

29. (Q). In the transmission of power over a long distance why are hollow cables used?
    (A). A hollow cable is more efficient in transmitting high-tension current since the latter current travels near the surface of the conductor, and current dissipation due to pure resistance, corona, and surge, is appreciably lessened. The cost of a hollow cable is comparatively low.
30. (Q). How could one find the power if the current is given in milliamperes and the potential in kilovolts?
    (A). Multiply milliamperes by kilovolts to get power in watts.
31. (Q). The frequency of a certain alternating current is 300 kilocycles, find the wave-length of the current.
    (A). Wave-length of the current = 30,000,000,000 cms ÷ 300,000 = 100,000 cms.
32. (Q). What is an insulator? Give a few examples of insulators.
    (A). An insulator is a non-conductor of electricity. Examples: Bakelites, rubber, fibre, wax, lucite, paraffin, etc.

SECTION IV

ELECTROMAGNETISM

1. (Q). What important factor enters into the induction of electromotive forces from the standpoint of direct or alternating current?
   (A). In the induction of electromotive forces, the intensity of the inducing current must be periodically changing. Usually A.C. is used for this purpose.
2. (Q). What is a transformer?
   (A). A transformer is an induction device for raising or lowering the voltage.
3. (Q). Give the component parts of a transformer.
   (A). A transformer consists of a central soft iron core having two separate copper wire windings, called primary and secondary, each insulated from the other.
4. (Q). In general, how many types of transformers are there?
   (A). Three types—step-up, step-down, and insulating transformer.
5. (Q). What is a step-up transformer?
   (A). A step-up transformer consists of a greater number of turns in the secondary than in the primary and raises the input voltage.
6. (Q). What is a step-down transformer?
   (A). A step-down transformer contains a greater number of turns in the primary than in the secondary coil, and it lowers the input voltage.
7. (Q). What is an insulating transformer? When is it used?
   (A). An insulating transformer consists of equal numbers of turns in both the primary and the secondary, and is used in heating the filaments of valve tubes on high potential X-ray generators.
8. (Q). What is a transformer constant?
   (A). It is the ratio of the primary coil turns to those in the secondary.
9. (Q). Why is a transformer carrying a large power immersed in oil?
   (A). Oil insulates the primary winding from the secondary winding, obviating the possibility of a spark-over. It also cools the transformer.

10. (Q). Can the voltage of a direct current be stepped up by a transformer? Why?
    (A). No. However, a rotary converter may be used before D.C. can be applied to a transformer.
11. (Q). At about what potential is the power from the generating plant transmitted to the city?
    (A). At about 250,000 volts.
12. (Q). What voltage is used in house-holds or office buildings?
    (A). 115-125, and 230-250 volts.
13. (Q). Give the transformer formula for power.
    (A). Primary power = secondary power ($I_1V_1 = I_2V_2$).
14. (Q). Give the transformer formula in terms of the voltage and wire turns.
    (A). $N_1 : N_2 :: V_1 : V_2$; where, N stands for turns, V for voltages, and subscripts 1 and 2 respectively for primary and secondary.
15. (Q). The power input to the primary of a transformer is 10 amperes at 120 volts. If the transformer constant is 1:100, what will be the voltage, and the current in the secondary?
    (A). The secondary voltage = 120 x 100 = 12,000 volts; and the current $10 \div 100 = .1$ ampere.
16. (Q). What is a motor?
    (A). A motor is a device to convert electrical energy into mechanical energy.
17. (Q). What is a condenser?
    (A). A condenser is a device for storing electric charges.
18. (Q). What is a rheostat?
    (A). A rheostat consists of a resistance coil for regulating electric current.
19. (Q). What is a choke coil?
    (A). A choke coil consists of a coil of copper wire having a slidable soft iron core, and is used for regulating electric current by changing the position of the iron core in the coil.
20. (Q). What is an autotransformer?
    (A). An autotransformer is a device to vary the voltage from zero to full input potential.

SECTION V

RECTIFICATION OF A. C. CURRENTS

1. (Q). What is rectification?
   (A). Rectification is the process of changing an alternating current into a direct current.
2. (Q). By what general ways can rectification be accomplished?
   (A). By mechanical means, by cuprous oxide plates, and by means of thermionic tubes.
3. (Q). What is a rectifier?
   (A). A rectifier is a device which changes an alternating current into a direct current.
4. (Q). What is a mechanical rectifier?
   (A). A mechanical rectifier is a rotary electric switch which causes the alternating current to flow only in one direction.
5. (Q). What is a thermionic rectifier?

(A). A thermionic rectifier is a vacuum tube having a heated filament and a comparatively cool anode, and is used to rectify A.C. A valve tube is the same as a thermionic rectifier.

6. (Q). What is plate rectification?
(A). Rectification by means of copper plates having alternate surfaces coated with cuprous oxide is known as plate rectification.

7. (Q). What is self-rectification?
(A). When the X-ray tube rectifies its own current, the process is known as self-rectification.

8. (Q). What are full-wave and half-wave rectifications?
(A). In full-wave rectification both of the alternations of a cycle are made to flow through the X-ray tube, while in half-wave rectification only every other alternation passes through the X-ray tube.

9. (Q). By what means can a full-wave rectification be obtained?
(A). A full-wave rectification may be obtained by means of a mechanical rectifier, plate rectifier, two-valve, four-valve, and six-valve arrangements.

10. (Q). By what means can a half-wave rectification be obtained?
(A). By means of the X-ray tube itself, and by a single valve arrangement.

11. (Q). What is a single-valve rectification?
(A). In this arrangement only a single valve tube is used to aid the X-ray tube in suppressing half of the transformer inverse potential.

12. (Q). What is a four-valve-rectification?
(A). The arrangement of four-valve tubes to produce full-wave rectification is known as four-valve rectification.

13. (Q). What is constant potential rectification?
(A). The rectification arrangement which generates a non-pulsating voltage and causes a continuous current flow through the X-ray tube is known as a constant potential rectification.

14. (Q). What is meant by a voltage-doubling generator?
(A). The rectification arrangement producing double the transformer voltage across the X-ray tube is known as a voltage-doubling generator.

15. (Q). What is meant by a voltage-tripling generator?
(A). In this case, the generator triples the transformer voltage before the latter is applied across the X-ray tube.

16. (Q). What is a Villard circuit? To what potential does it lend itself?
(A). It is a voltage-doubling circuit. Since only one-half of the X-ray tube voltage needs to be supplied by the transformer, the unit is used extensively for high-voltage work.

17. (Q). What is a Greinacher circuit?
(A). It is a constant-potential high-voltage circuit.

18. (Q). Is a constant-potential current pulsating?
(A). No. It is a continuous unidirectional current.

19. (Q). What type of current is generally used in deep therapy applications?
(A). Constant potential current.

20. (Q). In a thermionic rectifier, what is the effect of the temperature on the cathode filament?
(A). The higher the temperature of the cathode filament the greater the electron emission.

21. (Q). What is the effect of the applied voltage on the speed of the electrons?
(A). Increasing the potential will increase the speed of the electrons.

22. (Q). What is the saturation current in a thermionic tube?
    (A). With a given filament temperature, the saturation current is the constant maximum current obtainable from the filament no matter how much the applied voltage is increased.
23. (Q). Why is a rectifier used below the saturation point of the current?
    (A). So that the rectifier will not produce X-rays, and that the X-ray tube may discharge various milliamperes up to its rated capacity.
24. (Q). Why is an X-ray tube used beyond the saturation point?
    (A). Beyond the saturation point, the applied potential is expended only in increasing the kinetic energy of the electron.
25. (Q). How is the milliamperage in a thermionic tube controlled?
    (A). By the magnitude of the filament temperature.
26. (Q). Discuss the advantages of a four-valve rectification system over those of a mechanically rectified system.
    (A). A four-valve rectification operates quietly, produces no radio interferences, has no moving parts, requires no calibration from time to time, is not affected by weather conditions or altitudes, etc.
27. (Q). What is a potential indicator?
    (A). An electric instrument to pre-indicate the applied potential to the X-ray tube.
28. (Q). What is a polarity indicator? Where is it used?
    (A). It is an instrument, always installed in a mechanically rectified apparatus, to indicate the direction of the current flow through the X-ray tube.
29. (Q). What is a polarity commutator?
    (A). The electric rotary switch which permits only every other alternation of the current to pass through the polarity indicator.
30. (Q). What is a synchronous motor? When is it used?
    (A). A synchronous motor furnishes a constant speed synchronized with the frequency of the A.C. current. It is used to rotate the rotary switch of the mechanical rectifier.
31. (Q). On a 60-cycle current, how many revolutions does a rotary switch make per second? How many per cycle?
    (A). 30 revolutions per second. One-half revolution per cycle.
32. (Q). What is a stabilizer? In what section of the X-ray circuit is it connected?
    (A). A stabilizer, usually connected in the secondary circuit, tends to maintain a uniform current through the X-ray tube.
33. (Q). What is a Coolidge transformer?
    (A). It is a variable step-down filament transformer.
34. (Q). What is an X-ray transformer?
    (A). It serves to step-up the potential before it is applied to the X-ray tube.
35. (Q). What are X-ray aerials?
    (A). They are the overhead leads carrying the current from the rectifiers to the X-ray tube.
36. (Q). What are spark-gap spheres used for?
    (A). They serve to nullify the potential surges in the secondary current, and also in the calibration of the X-ray apparatus.
37. (Q). What is meant by the calibration of an X-ray machine?
    (A). The charting of a curve to indicate various kilovoltages in correspondence with various autotransformer buttons.

38. (Q). What is a milliammeter? Where is it placed in the X-ray circuit?
    (A). It is an instrument to indicate the current through the X-ray tube, and is connected in series with the X-ray tube.
39. (Q). What is a kilovoltmeter?
    (A). It indicates the voltage in kilovolts.
40. (Q). What method or methods are used in measuring the kilovoltage of an X-ray circuit?
    (A). Spark-gap method, electrostatic voltmeter, a pre-calibrated A.C. voltmeter connected at the center of the transformer secondary winding.
41. (Q). How does a high voltage drop in a valve tube affect the emission of X-rays?
    (A). A slight decrease in emission with an attendant increase in wave-length ensue.
42. (Q). Upon what two important factors is the life of a valve tube dependent?
    (A). The filament temperature and the applied potential.
43. (Q). To what extent is a diagnostic apparatus equipped with six valves superior to the four-valve machine?
    (A). It offers a higher specific loading of the tube, more homogenous radiation output, and reduction in exposure time.
44. (Q). What is meant by ripplage?
    (A). Waves of slight deviation from straight line phase in a constant potential curve.

SECTION VI

CATHODE RAYS AND X-RAYS

1. (Q). What is an electric discharge?
   (A). The passing of charged particles from one electrode to the other is known as electric discharge.
2. (Q). By what two general methods can an electric discharge be produced?
   (A). Gaseous discharge, and thermionic discharge.
3. (Q). How can a discharge be obtained in a partially gas-filled discharge tube?
   (A). By the ionization of the gaseous atom when a potential is applied.
4. (Q). How can a discharge be produced in a vacuum tube?
   (A). By having an incandescent filament as a source of negative ions and then applying a potential.
5. (Q). How is the milliamperage in a gas-filled discharge tube controlled?
   (A). By means of the applied tube potential, or by means of a rheostat.
6. (Q). How is the milliamperage through a vacuum tube controlled?
   (A). The temperature of the filament controls the milliamperage through a vacuum tube.
7. (Q). Is it necessary to use an alternating current or a direct current in order to produce electric discharge?
   (A). Either an A.C. or D.C. will produce an electric discharge.
8. (Q). What are cathode rays?
   (A). Cathode rays are a stream of electrons propagating at high speed from the cathode.
9. (Q). Are cathode rays produced by a direct current or an alternating current?
   (A). Generally by a direct or unidirectional current.

10. (Q). Can an alternating current produce cathode rays? How?
 (A). Yes, if it is first rectified.
11. (Q). What effects do magnetic fields have on cathode rays?
 (A). Cathode rays are deflected by a magnetic field.
12. (Q). How may the speed of cathode rays be controlled?
 (A). By means of the applied potential.
13. (Q). Can cathode rays be made to converge to a point?
 (A). Cathode rays can be converged to a point.
14. (Q). Do cathode rays penetrate matter?
 (A). Cathode rays penetrate aluminum of a thickness of as much as one centimeter.
15. (Q). When cathode rays impinge on matter with high velocity, what is the result?
 (A). When high velocity cathode rays impinge on matter of relatively high atomic weight, they produce X-rays.
16. (Q). Do thermionic emissions of cathode rays differ from those emitted from a cold cathode gas-filled tube?
 (A). There is no perceptible difference.
17. (Q). Why is it essential to have cathode rays in order to produce X-rays?
 (A). So as to be able to excite the atoms in the tube target to radiation.
18. (Q). What are X-rays?
 (A). X-rays are invisible electromagnetic radiations having the same nature as visible light, but of extremely penetrating character.
19. (Q). How are X-rays produced?
 (A). When high velocity cathode rays impinge on a metallic target, they incite the atoms in the target to radiation of X-rays.
20. (Q). By quantum theory, discuss the generation of X-rays.
 (A). When a cathode particle (electron) makes an inelastic collision with an atom of the target, one of the orbital electrons of the atom is displaced into another orbit. The atom in this state is unstable, and, therefore, the electron returns to its original orbit giving off a photon of X-radiation.
21. (Q). What per cent of the cathode ray energy incident upon the anti-cathode (anode) is transformed into X-rays?
 (A). Between .1 to .8 per cent.
22. (Q). Discuss the factors that influence the percentage output of X-rays.
 (A). The percentage output of X-rays is dependent upon the nature of the target metal, milliamperage of the tube, the applied potential, and the wave character of the potential.
23. (Q). How does the penetrativeness of X-rays vary with different substances?
 (A). The penetrativeness of X-rays varies with the density and the thickness of different materials.
24. (Q). What substances are transparent to X-rays?
 (A). Almost all organic substances, glass, paper, bakelites, wood, rubber, and to a certain extent aluminum.
25. (Q). What substances are opaque to X-rays?
 (A). Most organic substances, and calcium, lead, steel, iron, and compounds of these elements, are opaque to X-rays to varying degrees.
26. (Q). Do X-rays possess electrical polarity?
 (A). X-rays are neutral radiations.
27. (Q). At what velocity do X-rays propagate?

(A). They propagate with a velocity equal to that of light.

28. (Q). Can X-rays be focused to a point?
(A). X-rays can not be focused.

29. (Q). Can X-rays be influenced by electric or magnetic fields?
(A). Electric or magnetic fields have no effect on X-rays (with reservation).

30. (Q). What is the range of X-ray wave-lengths?
(A). 0.06 to 1100 angstrom units.

31. (Q). Are X-rays capable of affecting photochemically the sensitive emulsion of the radiographic film?
(A). All photographic films are affected by X-rays.

32. (Q). What action do X-rays have that make them of diagnostic value?
(A). Because X-rays in passing through the body produce shadows of various radiations dependent upon the densities of the different tissues, the shadowgraph thus produced on a film consists of the impressions of different body structures under exposures.

33. (Q). What effect do X-rays have on living matter?
(A). X-rays may stimulate or disintegrate living cells, depending on the magnitude of the radiation.

34. (Q). How can the penetrating qualities of X-rays be affected?
(A). The applied voltage affects the penetrating quality of X-rays.

35. (Q). What is the relation of the frequency of the X-rays to the atomic weight of the target metal?
(A). The higher the atomic weight of the target metal the higher the frequency of the X-rays produced from it.

36. (Q). What effect has the applied voltage on the wave-length and the frequency of the resulting X-rays?
(A). The higher the applied voltage, the shorter the X-ray wave-length, and the higher the frequency of the radiation.

37. (Q). How does the effective wave-length of X-rays vary in regard to voltage?
(A). The effective wave-length of X-ray radiation varies approximately with the square of the applied voltage.

38. (Q). How can the penetration of X-rays be controlled?
(A). The penetration of X-rays is controlled by the potential impressed on the X-ray tube.

39. (Q). In what relation does the penetrating quality of X-rays vary with the atomic weight of the target metal?
(A). The higher the atomic weight of the target metal, the higher the penetration quality of the X-rays.

40. (Q). What is a radiograph?
(A). A radiograph is a point-by-point delineation of the different densities of the object traversed by X-rays.

41. (Q). If X-rays penetrate all materials, how can they be employed to produce a radiograph?
(A). X-rays penetrate matter having various densities to varying degrees. Hence, the radiographic film receives varying quantities of X-ray intensities which are recorded on it producing a radiograph.

42. (Q). What is the relation of the penetration of X-rays to the thickness and the type of tissue?
(A). X-rays penetrate different tissues to varying depths, and the thicker a given tissue the more opacity it will offer to the radiation.

43. (Q). How does the air-content of different body structures affect the resulting radiograph?

    (A). The air-content of a body structure reduces the density of that part making it more transparent to X-rays.

44. (Q). What are soft X-rays? How are they produced?

    (A). Soft X-rays are long wave-length and less penetrating radiations. They are produced from metals of relatively low atomic weight, and from outer orbits of atoms of high atomic weight.

45. (Q). What are hard X-rays? How are they produced?

    (A). Hard X-rays are of short-wave length and have relatively high penetrating quality. They are produced from heavy metals used as target material, and from inner orbits of the atom.

46. (Q). What are X-rays of medium wave-lengths? What are they used for?

    (A). X-rays of medium wave-lengths have medium penetration qualities and are used to a large extent in radiography.

47. (Q). What are primary radiations?

    (A). The direct radiation from the focal spot of the X-ray tube is called primary radiation.

48. (Q). What are secondary radiations?

    (A). Radiations incited by the primary beam incident upon matter are known as secondary radiations.

49. (Q). What are scattered radiations? How are they produced?

    (A). The change of direction of the propagation of the primary beam as it traverses matter is known as the scattering of X-rays, and the rays thus scattered are called scattered radiations. Scattered radiations are produced from materials lighter than Aluminum, and from organic substances (patient).

50. (Q). What are characteristic radiations? How are they produced?

    (A). When primary rays become incident upon a metal (matter) heavier than Aluminum (such as, Iron, Nickel, Zinc, Copper, Tungsten, etc.) the primary radiation energy is transformed into a new radiation of relatively longer wave-length which is known as the characteristic radiation of that metal.

51. (Q). What are tertiary X-rays? What is their source?

    (A). The emission of X-radiation from matter irradiated by secondary rays is known as tertiary radiation. Its source is a tertiary target (matter).

52. (Q). How do secondary radiations affect the radiograph?

    (A). The secondary radiation when allowed to become incident unto the film contribute to the unsharpness of the radiograph.

53. (Q). How do scattered radiations affect the operator?

    (A). Since the scattered radiations are practically the same character as the primary beam, their effect on the operator is considered to be the same as that produced by the primary radiation.

54. (Q). How are secondary radiations prevented from reaching the film?

    (A). By interposing a Potter-Bucky diaphragm between the film and the object radiographed.

55. (Q). How are characteristic radiations prevented from reaching the film?

    (A). Partly by the patient, partly by the table-top, and partly by the Bucky diaphragm.

56. (Q). What properties do X-rays possess that make them of diagnostic value?

(A). Since X-rays penetrate different density tissue structures to varying depths, the resulting shadow recording consists of various density gradations which permit the diagnosis of these structures.

57. (Q). What inherent properties of a substance are a function of its relative opacity to X-rays?

(A). The density and the thickness of a substance are a direct function of its relative opacity to X-rays.

58. (Q). If soft tissue is more transparent to X-rays than bone tissue, why is a high-potential and low-milliamperage technic employed to obtain soft tissue detail?

(A). The advantages of this technic are that greater sharpness in the definition with well-balanced radiographic quality together with material reduction in milliampere-seconds and satisfactory exposure latitude are obtained.

59. (Q). If X-rays are used to disintegrate cancerous tissue underneath a normal tissue, for what reasons is the latter prevented from becoming amenable to the action of the radiation?

(A). Owing to the fact that the cancerous tissue is irradiated from four to six different directions, the normal tissue exposed to the rays at each portal receives only one-fourth to one-sixth of the radiation, and, therefore, the radiation effect on it is correspondingly curtailed.

60. (Q). How is the intensity (quantity) of X-rays determined?

(A). The intensity of X-rays is determined by the applied potential, the milliamperage, and the character of the target metal.

61. (Q). How is the penetration quality (wave-length) of X-rays determined?

(A). The penetration quality of X-rays is determined by the applied kilovoltage.

62. (Q). If X-rays are invisible, how can their presence be detected?

(A). X-rays can be detected by their action on the emulsion of the film, by causing fluorescent crystals to glow, by ionizing gases which they traverse, by their action to cause a change of color on certain chemical compounds, etc.

63. (Q). How can the X-radiation be restricted to the desired area?

(A). By means of a cone of appropriate size, or by a diaphragm.

64. (Q). When a more penetrating beam of X-rays is desired how is it obtained?

(A). By raising the kilovoltage.

65. (Q). When a high intensity (quantity) of X-rays is desired, how is it obtained?

(A). By increasing the milliamperage and the kilovoltage.

66. (Q). What tissues are the most sensitive to X-ray radiation?

(A). Lymphocytes and leukocytes, in general, are most radiosensitive.

67. (Q). Can X-rays produce stimulation in the tissues?

(A). X-rays in discriminating quantities will produce stimulative effect in the living tissue.

68. (Q). Give a few applications of X-rays other than in medical profession.

(A). X-rays are used in examining the interior structures of metal casting, sorting frost-bitten fruits, fitting shoes to customers, etc.

69. (Q). What properties of a Potter-Bucky diaphragm make it useful as an effective means of precluding the secondary radiations from the film?

(A). Because of its consisting of alternate layers of wood and lead strips placed on the radius of curvature of the X-ray beam with the focal spot

as the center, it precludes practically all rays emanating from sources other than the tube target.

70. (Q). What are filters? For what purpose are they used?

(A). Leather, sheet Aluminum, Copper, Zinc, Cobalt, or Nickel are used as filters to eliminate X-radiations of relatively long wave-lengths. They are used in both diagnostic and in therapy work.

71. (Q). On what factors is the quantity of X-rays generated at the target dependent?

(A). On the milliamperage, kilovoltage, character of target material, and target angle.

72. (Q). What voltage should be applied to an X-ray tube in order that a photon having a wave-length of .20 angstrom units may be produced?

(A). Voltage $=$ 12345 $\div$ Wave-length in angstrom units. Therefore, 12345 $\div$ .2 $=$ 61,725 volts. Ans.

73. (Q). If the frequency of an X-ray photon is 7.5×10^{18} cycles, what must be the voltage on the X-ray tube? What must be the velocity of the cathode rays or the electrons leaving the cathode?

(A). Wave length in Angstrom Units $= 3 \times 10^{10} \times 10^{8} \div 7.5 \times 10^{18} = .4$ A.U. Therefore, Voltage $= 12345 \div .4 = 30{,}862$ Volts. Velocity of electron $= 5.9 \times 10^{7} \sqrt{V} = 1.036 \times 10^{10}$ cm/sec.

74. (Q). A beam of cathode rays, having a mean potential of 75 KV is incident on an X-ray tube target. Find the frequency and the wave-length of the X-ray photons thus produced.

(A). Wave-length $= 12345 \div 75000 = .164$ A.U.

Frequency $= 3 \times 10^{10} \times 10^{8} \div .164 = 1.8 \times 10^{19}$ cycles/sec.

75. (Q). A certain beam is invisible, can produce visible light when incident on fluorescent subtances, and can be focused to a point. What is the nature of this beam?

(A). Cathode Rays.

76. (Q). Name five characteristic properties of X-rays.

(A). 1. X-rays are invisible electromagnetic vibrations of high penetrating power, 2. can not be focused, 3. propagate with the speed of light, 4. produce photochemical action on the sensitized surface of a film, and 5. have slight ionizing power.

77. (Q). What characteristics of X-rays make it necessary to use a Potter-Bucky diaphragm?

(A). Since X-rays upon striking matter produce secondary radiations which when absorbed by the film produce deleterious effect, the Potter-Bucky diaphragm is used to obviate this effect by absorbing the secondary radiations.

78. (Q). Explain the difference between a homogeneous and a heterogeneous X-ray beam.

(A). A homogeneous X-ray beam consists of uniform wave-lengths, while a heterogeneous X-ray beam consists of X-rays of different wave-lengths.

79. (Q). What is the most important agent in the production of X-rays at the X-ray tube target?

(A). Swiftly-moving cathode rays.

80. (Q). How do cathode rays produce X-rays?

(A). The kinetic energy of cathode rays is transformed into radiation energy

in the atoms of tungsten target.

81. (Q). To what type of radiation energy are X-rays closely related?
(A). Electromagnetic waves.

82. (Q). How do different types of radiation energies differ one from the other?
(A). By the difference of their wave-lengths and frequencies.

83. (Q). Name different electromagnetic radiations ranging from the shortest to the longest wave-lengths.
(A). Cosmic rays, gamma rays, X-rays, ultra-violet rays, visible rays, infrared rays, Hertzian waves, radio waves, and electric waves.

84. (Q). What form of energy immediately proceeds X-ray energy?
(A). Kinetic energy of cathode rays.

85. (Q). Upon what characteristic of X-ray energy is the controlling factor in obtaining contrast dependent?
(A). Upon the intensity (quantity) of the radiation.

86. (Q). By whom and when were X-rays discovered?
(A). X-rays were discovered in November, 1895, by Wilhelm Konrad Roentgen.

87. (Q). How is the term "X-rays" originated?
(A). Unaware of the character of the radiation emanating from his experimental tube, Roentgen named this radiation "X-Rays".

SECTION VII

X-RAY TUBES AND APPARATUS

1. (Q). How many types of X-ray tubes are in use now, in general?
(A). Two types—the ionic, and the electron tube.

2. (Q). What is an ionic type X-ray tube?
(A). An ionic type X-ray tube has a concave cathode and a flat disc anode. The tube contains a very small amount of gas at very low pressure. When the potential is applied the gas in the tube ionizes and furnishes a discharge current.

3. (Q). What is an electron type X-ray tube?
(A). An electron tube is a vacuum tube having a filament cathode and a solid copper anode with its target surface placed at some angle in respect to the cathode. The filament, when heated, furnishes the current through the tube.

4. (Q). Give the advantages and the disadvantages of both the electron type and ionic type X-ray tubes.
(A). The X-ray output from an ionic type X-ray tube is greater and the wave-lengths of the radiation are more homogeneous than an electron type X-ray tube furnishes. However, the current through the former type is not independent of the potential, while in an electron tube the potential can be varied in a wide range without affecting the tube current.

5. (Q). On what principle does an electron type X-ray tube function?
(A). On Edison Effect, which is emission of electrons from bodies heated to high temperatures.

6. (Q) What properties of an electron X-ray tube render it self-rectifying?
   (A). When the filament of an electron type X-ray tube is heated, it emits electrons which pass to the anode when the latter is charged positively; when the anode is charged negatively, no electrons can pass through the tube, thus the A.C. current becomes rectified.
7. (Q). What is the range of target angles in an X-ray tube?
   (A). From 10° to 75° with the vertical.
8. (Q). How is the focal area of an X-ray tube determined?
   (A). By the power rating of the X-ray tube—200 watts per square mm.
9. (Q). What relation has the temperature of the cathode filament to the milliamperage through the X-ray tube?
   (A). Increasing the filament temperature increases the tube milliamperage.
10. (Q). List the general types of Coolidge X-ray tubes.
    (A). Universal, diagnostic, oil-immersed, dental, deep therapy, industrial, and special high-voltage research tubes.
11. (Q). Discuss focal spot characteristics in relation to X-ray intensity.
    (A). The higher the atomic number of the focal spot metal the greater the intensity of X-rays. The density of the metal may affect the intensity to some extent.
12 (Q). Discuss the focal-spot characteristics in relation to radiographic quality .
    (A). The smaller the focal spot and the target angle, the greater the sharpness of the radiograph.
13. (Q). What is the range of area and thickness of the focal-spots?
    (A). The focus area ranges from 1.5 sq. mms. to 1 sq. cm., and the thickness varies from 1.7 mms. to 6 mms. or over.
14. (Q). Upon what principal factor does the rating of an X-ray tube depend?
    (A). Upon the area of the focal-spot—200 watts per sq. mm.
15. (Q). What is the maximum power that can safely be impressed on each square millimeter of the focal area?
    (A). 200 watts per sq. mm. in the case of a stationary target, and 250 watts per sq. mm. with a rotating-anode type X-ray tube.
16. (Q). What is a Benson focus? Line focus? Band focus? Round focus?
    (A). Benson focus is the name given to an oblong focal area. Line-focus and band-focus are same as Benson focus. When the focal area is round or oval, it is called round-focus.
17. (Q). What is the relative intensity of X-ray radiation at the area of effective focus?
    (A). About three times that of the rest of the radiation.
18. (Q). What portion of the total energy received at the anode is transformed into X-rays?
    (A). From 0.025% to 0.8%.
19. (Q). What are the chief objects in the development of modern X-ray tubes?
    (A). High power rating, and hence short exposure time, shock-proofing, X-ray proofing, and increase of flexibility of use of the tube.
20. (Q). Discuss why a universal X-ray tube is not operated self-rectified.
    (A). While operating, the target of the universal tube becomes incandescent and hence a source of electrons. Therefore, when impressed with an alternating potential the current will flow in both directions through the tube.
21. (Q). Describe the structural features of a diagnostic X-ray tube.

(A). The diagnostic X-ray tube consists of an evacuated glass envelope enclosing a tungsten filament cathode located in a molybdenum focusing cup, which serves to converge the cathode rays onto the anode. A heat radiatior is usually attached to the stem of the anode outside the tube.

22. (Q). Explain why the target of an X-ray tube should be kept cool.

(A). Since most of the kinetic energy of the cathode rays is transformed into heat at the target, it becomes highly essential that this heat be conducted away from the target in order to obviate the melting of this structure.

23. (Q). What methods are employed to cool the X-ray tube target?

(A). The target is cooled by means of metal radiators, by circulating water or oil through the anode stem, and by a stream of cold air.

24. (Q). What difficulties must be overcome in the construction of a high-voltage therapy tube?

(A). The accumulation of stray electrons on the glass near either end of the tube, spontaneous ionization due to inadequate tube vacuum, sparking over the outside of the tube when the glass arms are not placed apart at a sufficiently large distance, improper cooling of the target, and the character of the glass envelope.

25. (Q). How is the preclusion of the stray and secondary electrons from the glass envelope of an X-ray tube realized? Give two methods of attaining this end.

(A). To trap stray electrons in a hollow anode and to construct the central bulbar portion of the tube of metal, grounded so that the stray electrons will be attracted to earth.

26. (Q). Give the different types of X-ray tube envelopes now in general use, pointing out their practical advantages.

(A). Soft glasses of sodium or cerium base have been used in ionic type X-ray tubes but owing to their lack of resistivity to heat, lack of dielectric strength, and brittleness, they are being replaced by pyrex or boro-silicate glass which offers a high mechanical strength, high melting-point, and high electrical resistivity.

27. (Q). What effect has the target material on the tube pressure?

(A). The target material must be of high melting-point and low vapor pressure in order that a constant vacuum can be insured.

28. (Q). What inherent thermal characteristics of Copper and Tungsten render the combination an efficient target structure?

(A). Since tungsten has a melting-point approximately three times as high as copper, and copper has thermal conductivity three times as high as tungsten, the combination permits the use of relatively high specific load on the target.

29. (Q). Discuss the cathode structure as regards the convergence of electrons.

(A). The convergence of electron emission is dependent on how deep the cathode filament is placed in the focusing-cup.

30. (Q). If the focal-spot size is known, how may the rating of the tube be determined?

(A). The rating of the tube is determined by multiplying the focus area in sq. mms. by 200 watts.

31. (Q). Account for the distinctive features of a rotating-anode type X-ray tube.

(A). A rotating-anode X-ray tube offers the advantage of permitting the use of considerably larger amounts of power (seven to eight times) with a relatively small focal spot.

32. (Q). How does the rotating-anode X-ray tube render the reduction of exposure time to minimum values?
    (A). Owing to high load capacity of the rotating-anode, the exposure time is correspondingly shortened.
33. (Q). Account for the advantages presented by ray-proofed and electrically safe X-ray tubes.
    (A). Higher energy ratings, improved mechanical strength, minimum danger of accidental breakage, increased protection against punctures, and greater flexibility of use.
34. (Q). What effect has the focus area on the radiographic quality?
    (A). The radiographic quality is an inverse function of the focus area—the smaller the focus area the better the radiographic quality.
35. (Q). What effect has the target angle on the radiographic quality?
    (A). With a smaller target angle the effective focus area decreases, and hence the radiographic detail is markedly improved.
36. (Q). What effect has the atomic number of the target on the radiographic quality?
    (A). With a target of high atomic number the radiographic quality is greatly enhanced.
37. (Q). What effect has bias in an X-ray tube?
    (A). Bias at relatively low voltages limits the production of X-rays.
38. (Q). A certain X-ray tube has a cracked tungsten focal spot, and produces apple-green fluorescence during operation. To what condition of the tube are these indicant?
    (A). If the crack does not extend to the copper anode, the fluorescence has no particular significance, as it is due to stray electrons hitting the pyrex envelope.
39. (Q). State some of the causes of X-ray tube punctures.
    (A). By making a grounded contact with the tube when it is operating, due to the high electrostatic field between the inside and outside surfaces of the glass, and by starting up a high-voltage tube when cold.
40. (Q). How do rising temperatures affect the emission of electrons?
    (A). The emission is directly proportional to the temperature of the filament.
41. (Q). How may the milliamperage through an X-ray tube be varied?
    (A). By varying the temperature of the filament.
42. (Q). What is the effect of voltage on the speed of cathode rays?
    (A). The speed of cathode rays is a direct function of the applied voltage.
43. (Q). How can the focal spot of an X-ray tube be measured?
    (A). A pin-hole photograph of the focus can be made by interposing mid-way between the target and the film a sheet of lead having a bore of about 1 mm. in diameter and radiographing the film.
44. (Q). If the maximum load-carrying cappacity of a tube is 88 Kv.P., 100 M.A., and ½ second, under what conditions would one be justified to use one second?
    (A). By decreasing the kilovoltage in accordance with the tube rating charts furnished by the manufacturer.
45. (Q). What apparatus is used to control the heat of the tube filament?
    (A). A step-down filament transformer also known as a Coolidge transformer.
46. (Q). When a more penetrating X-ray beam is desired, how is it obtained?
    (A). By increasing the kilovoltage applied to the tube.
47. (Q). If the filament of the X-ray tube fails to light, what are the probable reasons?
    (A). 1. The current-carrying wires to the filament having been disconnected,

or, 2. twisted so that the current to the filament is short-circuited. 3. The cathode filament is burned out. 4. Defective main switch.

48. (Q). What metals are used as X-ray tube radiators?
(A). Copper, iron, molybdenum, aluminum, nickel, etc.

49. (Q). What is meant by fine, medium, and broad focus tubes? What tube characteristic is determined by the size of the focal spot?
(A). Fine focus tube has a small focal area; a broad focus tube has a large focal area, and medium focus is applied to a focus size intermediate to the former two foci. The load-carrying capacity of the tube—rating.

50. (Q). What radiographic relation determines the size of the focal spot to be used?
(A). It depends upon the magnitude of detail required in the radiograph. For fine detail work a fine focus, and for gross detail a broad focus tube is used.

51.(Q). What type of X-ray tube will give the optimum detail?
(A). A fine line-focus tube will give the optimum detail.

52. (Q). How does a proper cooling system increase the load rating of an X-ray tube?
(A). Since the load rating of the tube is a function of the target temperature, sustaining the target at a low temperature will permit the use of higher power on the tube.

53. (Q). How are the maximum energy ratings of exposures and the frequency with which they can be repeated determined?
(A). By the kilovolt-ampere-second cooling charts furnished by the manufacturer.

54. (Q). What is a filament transformer?
(A). It is a step-down variable transformer.

55. (Q). What is a main X-ray transformer?
(A). The transformer which furnishes the high voltage to the X-ray tube.

56. (Q). What is an autotransformer, and why is it used?
(A). An autotransformer is a device to vary the voltage to the primary side of the X-ray transformer from a minimum to the full input voltage.

57. (Q). What are cones? Why are they used?
(A). A cone is an iron or steel cylinder sometimes lined with sheet lead and mounted outside and opposite the X-ray tube target, and serves to restrict the area of radiation.

58. (Q). What is a Potter-Bucky diaphragm? How is it used?
(A). It is a device to prevent secondary radiations from reaching the film. It is interposed between the patient and the film, and its movement is synchronized with the time of exposure.

59. (Q). What are filters? Why are they used?
(A). A filter is a sheet metal (aluminum, copper, tin, zinc, etc.) to eliminate X-radiation of unwanted wave-lengths from the exposure field.

60. (Q). What is an impulse timer?
(A). It is a device which times the exposure in terms of alternations passing through the X-ray tube.

61. (Q). What methods are there to determine the accuracy of a timer?
(A). The spinning-top method, and pin-hold sheet lead method.

62. (Q). What advantage has an autotransformer over a rheostat?
(A). The autotransformer varies the input voltage without appreciably wasting the input power, while a rheostat may be made to vary the voltage at the expense of power dissipated in the form of heat.

63. (Q). What is a serialograph?
    (A). The serialograph (Westinghouse trade name) is an automatic spot film device consisting of a fluoroscope and means for holding a cassette. It serves both as a fluoroscope and as a cassette holder.

64. (Q). What is a fluoroscope? How does it function?
    (A). A fluoroscope is a device consisting of a fluorescent screen mounted in a metal frame covered with lead glass. In the presence of X-rays the screen glows in direct proportion to the intensity of the radiation, producing visual impressions of the densities traversed.

65. (Q). What are the essential parts of an X-ray generating apparatus?
    (A). An autotransformer, X-ray transformer, filament transformer, X-ray tube, ammeter, milliammeter, kilovoltmeter, timer, and generally, a table.

66. (Q). What significance is held by the calibration of an X-ray apparatus? Should all X-ray machines be calibrated before they are put into use?
    (A). In order to determine the kilovoltages obtainable from different autotransformer buttons with a given milliamperage, all X-ray machines are calibrated before they are put into use.

67. (Q). Give three methods of determining the potential in the high tension circuit of an X-ray apparatus.
    (A). Sphere-gap method; electrostatic voltmeter method; and, a direct-reading method consisting of a voltmeter connected across the center of the X-ray transformer secondary and calibrated to read in kilovolts.

68. (Q). When is a polarity indicator used? When not used?
    (A). On a mechanically rectified apparatus. Self-rectified, tube rectified, and plate rectified circuits do not need a polarity indicator.

69. (Q). What is meant by grounding?
    (A). Establishing an electrical connection from any portion of the circuit to earth is called "grounding".

70. (Q). At what voltage is the grounded portion of a circuit?
    (A). At zero voltage.

SECTION VIII

RADIOGRAPHIC EXPOSURE FACTORS

1. (Q). How is the radiographic density of an image determined?
    (A). By the quantity of X-ray intensity reaching the film.

2. (Q). List the factors influencing the amount and intensity of the X-radiation reaching the sensitized surface of the film.
    (A). Kv.P., M.A. exposure time, focal-film distance, patient thickness, cone, diaphragm, filter, etc.

3. (Q). How does a Bucky diaphragm affect the radiation reaching the radiographic film?
    (A). It absorbs 70 to 75% of the primary radiation.

4. (Q). How can the X-ray radiation be restricted to the desired area?
    (A). By means of a diaphragm or a cone of appropriate size.

5. (Q). What is the most important physical factor in obtaining good detail?

(A). Size of the focal spot.

6. (Q). What factors determine the magnitude of distortion in a radiograph?
   (A). Focus area, focal-film distance, object-film distance, tube alignment, and movement of part.
7. (Q). How is an optimum contrast in a soft tissue obtained?
   (A). By using high-kilovoltage and low-milliamperage technic.
8. (Q). Give seven factors that contribute to the obtaining of an optimum detail.
   (A). Small focus area, large focus-film distance, small object-film distance, high definition screens, complete immobilization, Potter-Bucky diaphragm, and short exposure time.
9. (Q). What is meant by good screen contact?
   (A). That means the film is uniformly in close contact with the intensifying screens.
10. (Q). Give electrical and physical conditions that have bearing on the radiation output of an X-ray tube.
    (A). Kilovoltage, milliamperage, character of target material, whether the current is constant or pulsating, and whether the tube is air-cooled or water-cooled.
11. (Q). What relation has X-ray intensity to radiographic density?
    (A). The radiographic density is directly dependent upon the intensity of X-rays.
12. (Q). In a technic with 52 Kv.P., 40 M.A., 5 seconds, and 30 inches, a proper radiographic density is obtained. All other factors being constant, how much should the milliamperage be increased in order to double the radiation intensity? How much will the radiographic density be increased?
    (A). The milliamperage should be increased by 40 M.A. The radiographic density will be doubled.
13. (Q) A square lead plate placed 40 cms. from the X-ray target is removed to a distance of 60 cms. What relative radiation intensity will reach the plate?
    (A). $(40)^2 : (60)^2 :: X : 100\%$ and, $X = 160{,}000 \div 3600 = 44.4\%$. Ans.
14. (Q). In a certain technic, the focal-film distance is 36 inches, and the exposure time is 4.4 seconds. At what focal-film distance could an exposure time of 2 seconds be used?
    (A). 24.2 In. Ans.
15. (Q). In a technic, 54 Kv.P., 20 M.A., 16 seconds, and 60 inches, a proper radiographic density is obtained, using double intensifying screens and no Bucky diaphragm. 1. What will be the exposure time if Bucky diaphragm is used? 2. With Bucky diaphragm, what will be the exposure time if M.A. is changed to 30? 3. Without Bucky diaphragm, what will be the exposure time with 10 M.A., using cardboard at a distance of 25 inches?
    (A). 1. $16 \times 3.5 = 56$ seconds. Ans.
    2. $56 \times 20 = X \times 30$ and, $X = 56 \times 20/30 = 37.33$ seconds.
    3. $37.33 \div 3.5 = 10.66$ and, $10.66 \times 30/10 = 31.98$ seconds.
    $31.98 \times 10 = 319.8$ seconds.
    $319.8 : (60)^2 :: X : (25)^2$ and $X = 55.5$ seconds. Ans.
16. (Q). When proper radiographic detail can not be obtained due to inability to approximate part to film what change in technic may be employed?
    (A). Increase the focus-film distance appreciably.

SECTION IX

TARGET-FILM ALIGNMENT

1. (Q). What relation is borne by the object-film distance to radiographic distortion?
   (A). The smaller the object-film distance the less the radiographic distortion.
2. (Q). Discuss the factors requisite to the obtaining of the least degree of magnification in the radiographic image.
   (A). Large-focus-film distance consistent with radiographic technic, small object-film distance, and proper target-object-film alignment.
3. (Q). How may the tendency for the structures remotest from the recording surface be offset from becoming superfluously enlarged?
   (A). By making the focus-object distance large and object-film distance small.
4. (Q). What conditions are prerequisite to the securing of the optimum radiographic quality in an image?
   (A). Smallest focal area consistent with impressed power, large focus-film distance, small object-film distance, proper tube alignment, proper kilovoltage, proper milliampere-seconds, complete immobilization of the patient, and insertion of a Potter-Bucky diaphragm when desirable.
5. (Q). A patient's part lodging a bullet is placed against a fluoroscopic screen which is 22 inches from the X-ray tube. When the tube is shifted 4.5 inches to either side from the central position, the image moves through a distance of 2 inches. Find the depth of the bullet from the fluoroscope.
   (A). $4.5 : 2 :: (22 - X) : X$ and, $X = 6.75$ inches from fluoroscope.
6. (Q). In case two views at right angles can not be realized, what relative procedure must be undertaken to accomplish this purpose?
   (A). Take a stereoradiograph.
7. (Q). Why is it necessary to make a stereoscopic exposure at an anode-film distance greater than 25 inches?
   (A). The radius of curvature of the Bucky is between 27″ to 30″ and only at these distances optimum efficiency from the Bucky diaphragm is obtained.
8. (Q). Of what diagnostic importance are stereoradiographs?
   (A). Stereoradiographs reveal the true perspective of objects and their correct spatial relation to each other. They are particiularly valuable in eliminating the complication presented by overlapping structures by revealing them in their true relation in space.
9. (Q). Give the quality of illumination most favorable for diagnostic interpretation of a radiograph.
   (A). The light from an illuminator fitted with blue-tinted, flashed opal glass and a proper bulb is very satisfactory.
10. (Q). What important place is held by the use of a rotating-anode X-ray tube in realizing the least degree of movement?
    (A). The high load capacity of a rotating anode tube permits a material reduction in exposure time, and hence in degree of movement.
11. (Q). Since involuntary movement of the viscera can not be controlled, what procedure must be followed in order to reduce unsharpness due to movement to a minimum?

(A). Reduce the time of exposure to a minimum.

12. (Q). What is the principal ray?

(A). The X-ray beam issuing from the focus at right angles to the axial length of the tube.

13. (Q). What is the relation of the principal ray to the alignment of the patient and the film?

(A). The principal ray should be directed (perpendicularly) to the center of the exposure area.

14. (Q). In determining the position of the fluid level in the chest for subdiaphragmatic abscess, which position should be employed?

(A). Patient in erect position, AP or PA.

15. (Q). A patient's leg, 6 inches wide, is placed 20 inches from the focal-spot, and radiographed. The resulting image is enlarged by 2 inches. What must have been the focal-film distance?

(A). $6 : 8 : : 20 : X$ and, $X = 8 \times 20/6 = 26.6$ inches. Ans.

SECTION X

THE RADIOGRAPH AND FACTORS AFFECTING IT

1. (Q). Give the composition of a radiographic emulsion pointing out the inherent characteristics responsible for its radiosensitivity.

(A). The emulsion of a radiographic film consists of Silver Bromide, Gelatin, and a sensitizer. Silver Bromide in the presence of Gelatin forms "centres" which when sensitized with appropriate sensitizer become extremely radiosensitive.

2. (Q). How does the latent image render the silver salt of the emulsion to become amenable to the action of a reducing agent?

(A). When X-rays fall on the "centres" a photochemical change of catalytic character occurs, making the Silver Bromide in the emulsion amenable to reduction by the developer.

3. (Q). State the steps in the processing of an exposed film.

(A). The exposed film is immersed in the developer, rinsed with water, and then transferred to the fixer. It is then taken out and washed thoroughly in tap water and set aside to dry.

4. (Q). Give the ingredients of a developer, and a fixer, and state the function of each chemical in the respective solutions.

(A). The developer consists of Metol (Elon) which is a reducing agent; Hydroquinone—also a reducing agent; Sodium Sulphite—a preservative of the solution; Sodium Carbonate—facilitates the action of the developer on emulsion, and keeps solution alkaline; Potassium Bromide—clears the blacks and whites of the radiograph (also, a buffer). Water—a solvent. The fixer consists of:—Sodium Thiosulphate—dissolves all unaffected Silver Bromide from emulsion; Sodium Sulphite—preservative; Chrome-Alume and Sulphuric Acid—hardening agents. Water—a solvent.

5. (Q). Of what radiographic value is the standardized time-temperature processing?

(A). To determine whether the impaired density of a radiograph is due to the magnitude of the kilovoltage, milliampere, or the exposure time. Also,

to limit chemical reaction in the emulsion.

6\. (Q). Explain why 65° F is the optimum temperature for development?
(a). Above 65° F, there is a tendency of the gelatin of the emulsion to excessively soften.

7\. (Q). To what factors is the over-density of a radiograph attributable?
(A). Over-exposure, high milliamperage, or high kilovoltage.

8\. (Q). How can a high density radiograph be corrected?
(A). By immersing the radiograph in a reducer.

9\. (Q). What factors render anticipation on brown stains?
(A). Out-dated film, handling, negligence to rinse film before transferring it to the fixer, high-temperature development, and a weak fixer.

10\. (Q). Enumerate preventive measures in producing a radiograph free of artefacts.
(A). To thoroughly clean table-tops, cassettes, tips of cones; to avoid marking table-tops or cassettes with paint containing lead or heavy metal compounds.

11\. (Q). What tendency is indicated by an exhausted fixing bath on the radiographic emulsion?
(A). Brown stains.

12\. (Q). Explain why a red or green safelight does not appreciably affect the emulsion of the film.
(A). The emulsion of the film does not readily respond photochemically to wave-lengths issuing from safelights, due to its characteristic sensitivity to other wave-lengths particularly to blue-violet.

13\. (Q). To what extent is a dry unexposed film susceptible to the illumination from a safelight?
(A). A dry film placed a few feet from the safelight can be exposed to it about one-half minute with safety. The emulsion is less sensitive when wet.

14\. (Q). Does the focal-spot area affect the radiographic density?
(A). It does not affect.

15\. (Q). What distance factors are responsible for radiographic distortion?
(A). Focus-film distance, and object-film distance.

16\. (Q). If the radiograph has Bucky lines on the sides, what is the cause of this condition?
(A). The X-ray tube is too close to the Bucky diaphragm.

17\. (Q). If the Bucky lines are recorded only on one side of the radiograph, what is the cause of this condition?
(A). The X-ray tube is out of correct alignment.

18\. (Q). What is the cause of Bucky lines when present all over the radiograph?
(A). The movement of the Bucky is not properly synchronized with the timer.

19\. (Q). What factors are responsible for the production of a properly-balanced radiograph?
(A). Focus area, target-film distance, immobilization, proper radiographic factors, and standardized time-temperature processing of the film.

20\. (Q). What is the effect of the double-intensifyig screens on the radiograph?
(A). They have a tendency to increase unsharpness of the radiographic detail.

21\. (Q). What determines the speed of the intensifying screens?
(A). The size of the crystals of the fluorescent chemical—the larger the crystal, the faster the screen.

22\. (Q). What are "centres" in a radiographic film?

(A). "Centres" may be considered as elemental units or nuclei of detail.

23. (Q). What is meant by "latitude" of a radiographic film?
(A). It is the permissible deviation of the density of a radiograph with a resultant retention of diagnostic features.

SECTION XI

ELECTRICAL SAFETY AND X-RAY PROTECTION

1. (Q). State some of the electrical measures to be considered in working in X-ray quarters.
(A). For full information, read the introduction of Chapter XX, and also Section 3 of same chapter.

2. (Q). Of what significance is the grounding of the X-ray primary circuit?
(A). It produces a material reduction in electrical hazards in case an accidental human contact is made with bare wires.

3. (Q). How much protection do safety devices offer in preventing accidental shock from high tension?
(A). So long as no human contact is made with live wires. They offer little or no absolute protection.

4. (Q). What impetus in the manufacture of X-ray appartus is given from the standpoint of electrical safety?
(A). All high tension parts are well insulated and grounded so that accidental contact with the parts of the circuit is impossible.

5. (Q). What properties of X-rays make it necessary to preclude them from living cells?
(A). Because undue exposure to X-rays causes erythematous, and, in more advanced cases, necrotic, reaction in the living cells, it is necessary to preclude the radiation from the living cells.

6. (Q). Which tissue cells exhibit the highest radiosensitivity?
(A). Lymphocytes, and Leukocytes in general.

7. (Q). Is sterilization by X-rays subject to permanent degeneration of the germ cells?
(A). No. The germ cells become infertile only temporarily.

8. (Q). State the chief determinant as to whether the necrotic reaction as a result of undue exposure to X-rays will occur in the peripheral or in the deep-lying tissue structures.
(A). The condition is dependent upon the effective wave-length of the radiation and the degree of its penetration.

9. (Q). Give steps leading to the complete disintegration of a tissue structure by X-radiation.
(A). Read Section 2, Chapter XX.

10. (Q). What protective measures can be employed to screen off X-rays from the operator?
(A). By means of lead glass screens, lead-impregnated aprons, and gloves, by providing ray-proof shielding around the entire X-ray tube except its portal, and by covering the fluoroscopic screen with lead glass of adequate thickness.

11. (Q). On what consideration are the estimates for producing an erythema reaction based?
    (A). Based on distinct reddening of the skin as a result of irradiation by X-rays.
12. (Q). What is an erythema dose?
    (A). An erythema dose is that amount of X-radiation which just produces distinct reddening of the skin—600r to 850r depending on the physical disposition of the individual.
13. (Q). How much is the proposed permissible tolerance dose per day?
    (A). A maximum of 0.228r per sq. cm. per day.
14. (Q). Discuss the safe exposure limits to a single area of the human body.
    (A). See Section 2b, Chapter XX.
15. (Q). If a patient complains of static, how can it be eliminated?
    (A). By having the patient hold a metal part of the apparatus which is grounded.
16. (Q). What improvements in modern X-ray equipment render flexibility of use and unrestricted movement of the apparatus?
    (A). Production of ray-proof tubes with absolute electrical safety together with adequate design of the apparatus.
17. (Q). Why is proper ventilation of necessity in an X-ray therapy room?
    (A). Primarily to eliminate Nitrous Oxide gas, and Ozone prevalent in an atmosphere irradiated by X-rays.
18. (Q). Give the essential conditions in promoting hygienic atmosphere in X-ray rooms.
    (A). Proper ventilation, effective lighting, and sunshine where possible, and having the X-ray laboratory not lower than ground level.
19. (Q). What precautions are necessary in resorting to help in immobilizing the patient?
    (A). To keep the attendant in safe distance from electric hazards, and from both primary and (where possible) from secondary X-radiations.
20. (Q). Of what importance are Aluminum filters in radiography?
    (A). To filter off long wave-length X-rays which have deleterious effects both on the patient, and on the sharpness of the radiograph.
21. (Q). How are the lead-equivalent screening powers of different materials determined?
    (A). By comparing the X-ray protective power of 1-mm sheet lead with equivalent thicknesses of various materials.

SECTION XII

ANATOMY AND DIAGNOSTIC TECHNIC

1. (Q). What are landmarks? What radiological importance do they present?
   (A). Landmarks consist of definite anatomical regions, or parts, which aid in the centralizing the area under consideration to the film.
2. (Q). Give the division of the skeletal system.
   (A). Axial Skeleton:—Cranium, face, vertebrae, sternum, and ribs. Appendicular Skeleton:—Upper extremities, and lower extremities.
3. (Q). Name the bones constituting the skull.

(A). Occipital, parietal, frontal, temporal, ethmoid, and sphenoid.

4. (Q). Name the bones forming the vertebral column.
   (A). Cervical, thoracic, lumbar, sacral, and coccygeal vertebrae.
5. (Q). What bones comprise the shoulder?
   (A). Portion of scapula, lateral half of clavicle, and (proximal end of humerus).
6. (Q). What bones constitute the pelvis? Give the articulations of the pelvic bones.
   (A). Ilium, os pubis, os ischium, sacrum, and coccyx. Articulation:—Ilio-sacral, sacro-lumbar, ilio-pubic, ilio-ischium, ischio-pubic, pubic joint, and acetabulum.
7. (Q). What are the accessory nasal sinuses?
   (A). Frontal, ethmoid, sphenoid, and maxillary sinuses.
8. (Q). What views are ordinarily taken of any part?
   (A). Two views at right angles—AP, or PA; and lateral.
9. (Q). If it is not convenient to take two views at right angles to each other, what other views are resorted to?
   (A). Take stereoradiographs.
10. (Q). When the object can not be positioned closer to the film, what technic may be employed to secure good detail?
    (A). Increase object-focus distance consistent with permissible tube rating.
11. (Q). When the gall-bladder is obscured by the vertebral column, what position may be employed for better visualization?
    (A). A semi-oblique position, by lifting the right side above and below the region of the gall-bladder by means of sand bags.
12. (Q). Name the teeth in their order in the adult mouth.
    (A). Upper set:—3 molars, 2 premolars, 1 canine, 4 incisors, 1 canine, 2 premolars, and 3 molars. Lower set is same as upper.
13. (Q). For a complete radiodontic examination of the lower jaw, what structures should be included in the radiograph?
    (A). Body of the mandible, posterior maxilla, angle of the mandible, ramus of the mandible, temporomandibular articulation, and the bones of the face.
14. (Q). Of what prosthetic importance are extra-oral and profile radiographs?
    (A). The information so secured from these radiographs provide tangible records for comparing the natural relationship of the teeth and soft tissue structure before and after completion of the denture.
15. (Q). What is an ionization chamber?
    (A). It is a device containing a definite quantity of air at atmospheric conditions; which air becomes ionized when a beam of X-rays traverses it, producing an ionization current through it.
16. (Q). How is the X-ray dose in roentgen therapy measured?
    (A). The ionization current produced in the chamber is recorded on an instrument known as Mecapion which records X-ray intensity or dosage in roentgens.
17. (Q). In what units is the therapeutic dosage of X-rays measured?
    (A). In roentgens.
18. (Q). What is a roentgen? Define it.
    (A). It is a unit of X-ray intensity. A roentgen is that quantity of X-radiation which produces in 1 Cc of air at standard conditions (secondary electrons fully utilized, and wall effect avoided), a charge of 1/3000 micro-coulomb, or an ionization current of 3.33×10^{-10} ampere.

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